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THE COVER — Echo suppressor equipment (opposite page) developed at Bell Telephone Laboratories and shown installed in the Long Lines No. 1 office in New York. A. F. Richardson, Long Lines Engineer (left), and G. M. Phillips, Bell Laboratories, observe relay operation.

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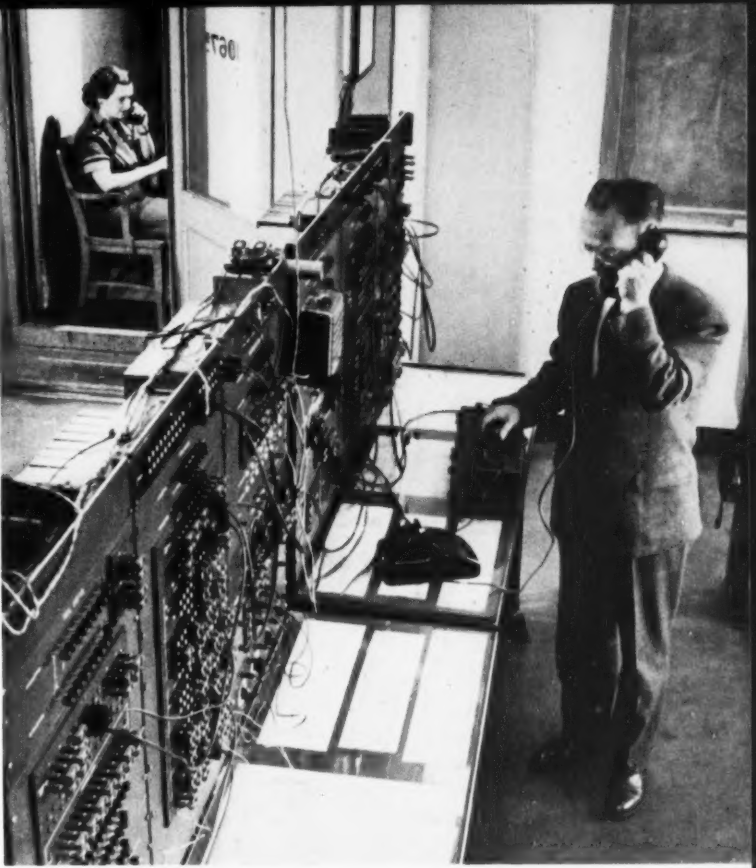
Echo and its Effects on the Telephone User



G. M. PHILLIPS *Transmission Engineering*

Echo, a nymph in Greek mythology who for love of Narcissus pined away until nothing remained but her voice, lends her name to the familiar reflection of sound frequently heard in the hills. Under such conditions, echoes may be pleasant enough, but on long-distance telephone circuits they become annoying, and can even make it difficult to carry on a conversation. Telephone circuits must be so designed that users do not hear these objectionable echoes.

Two conditions are necessary to produce an audible echo. First, there must be some obstacle in the path of the transmitted sound that reflects an appreciable part of the energy back toward the source. Second, the reflector must be far enough away so that there is a perceptible time delay between the original sound and that returning from the reflector. Conditions analogous to these sometimes occur on a long-distance telephone circuit, producing electrical echoes that are effectively converted to sound echoes by a customer's telephone set.

To the listener, a telephone echo makes a talker's voice sound as if it were coming through a hollow pipe and he has difficulty understanding what is said. The talker also gets the impression that he is speaking into a hollow pipe, but the echo has a more disconcerting effect on him; while his mind and voice are trying to form one sound or syllable, his ears are hearing a different sound. These undesirable echo effects are increased as the delay in time between the original sound and the echo increases. With a loud echo, the effect on a talker may become so serious, as the delay time is increased, that he slows down his speech, then begins to stammer and stutter, and finally stops speaking. Most people find it difficult to talk through a loud echo that is delayed a quarter of a second or more.

This fact was sometimes used by army medical examiners to detect would-be draft dodgers who were feigning deafness. The subject was asked to read a passage aloud into a transmitter, and his voice, after passing through a variable delay circuit, was fed to a receiver on his ear. The examiner gradually increased the amount of delay and observed the effects on the talker. A truly deaf person would continue reading aloud at a steady rate as the delay time was increased. A malingerer, however,

Above — The author conducts an echo judgment test. Mrs. Christine Scanlon acts as an observer.

would become so disturbed by the experience of voicing a syllable and hearing, not the sound he expects, but the previous syllable, that his speech would slow down. It would be obvious that speech was difficult for him as the delay time increased.

Echoes are produced in a long four-wire telephone circuit by the reflections of electrical energy that occur at the terminating sets at each end of the circuit. These terminating sets convert the circuit from a four-wire to a two-wire line; the amount of electrical energy reflected depends upon the degree of impedance balance between the two-wire part of the circuit, usually a toll connecting trunk, and a balancing network in the four-wire terminating set. The better the impedance balance, the greater is the loss in reflected energy, called the return loss, returned to the sending end of the circuit.

The way in which telephone echoes are formed in a long four-wire circuit is illustrated in Figure 1. As shown, energy representing a talker's voice arrives at the listener's end of the circuit by way of the heavy line labeled DIRECT TRANSMISSION. Since in general, the impedance balance at the listener's four-wire terminating set is not perfect, a part of the direct transmission energy is reflected back toward the talker. This is indicated by the line labeled FIRST ECHO-TALKER. When the reflected energy arrives at the talker's end of the circuit it will have traveled twice the length of the circuit. The speech sound will therefore be heard by the talker a fraction of a second after he has spoken it. A part of this first echo may also be reflected at the talker's four-wire terminating set and be sent again toward the listener. This is indicated by the line labeled FIRST ECHO-LISTENER. If the impedance balance at both ends of the circuit are poor, causing low return losses, and if the losses on the four-wire line are low, multiple echoes may be heard by both talker and listener.

Ordinarily the round-trip loss is sufficient to prevent such multiple echoes, but they may occur, in rare instances, if trouble conditions exist. For talker echo, the round-trip loss is twice the loss of the telephone circuit plus the return loss at the far end of the line. Round-trip loss for listener echo includes the return losses at both ends of the circuit and is therefore greater than the talker echo round-trip loss. For this reason, listener echo generally need not be considered in engineering toll circuits, since it will be well within bounds if talker echo is held to tolerable limits.

Since the undesirable effects of telephone echoes increase as delay times become greater, more round-trip loss is necessary at the longer delays to reduce the loudness of echoes. The rate at which round-trip loss must be increased with increasing delay is illustrated by the curve in Figure 2. This curve, determined from judgment tests made in 1953, shows the relation between round-trip delay and the minimum round-trip loss required to attenuate the echo enough to provide commercially tolerable conditions in the judgment of an average listener. "Commercially tolerable" means that although an echo was discernible it was not loud enough to be objectionable. The curve represents the average tolerance to echo of all the listeners, but any individual may differ from the average by a considerable amount. An analysis of all the test data indicated that a large group of individuals would have differences in echo tolerance following a normal law of distribution. The standard deviation was estimated to be 5 db, meaning that 68 per cent of the individuals would have a tolerance to echo lying within $\pm$ 5 db of the

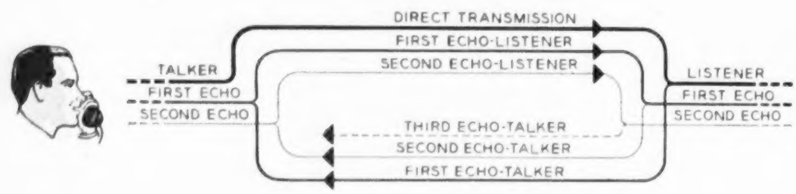


Fig. 1 — Telephone echo paths in a typical four-wire circuit.

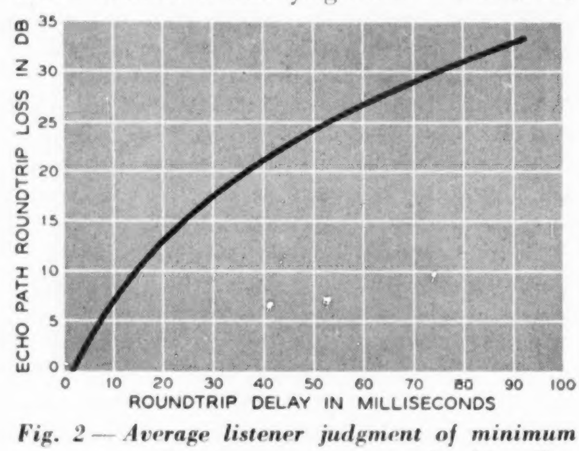


Fig. 2 — Average listener judgment of minimum echo attenuation necessary for just tolerable talker echo conditions on modern telephone sets.

average curve. The remaining 32 per cent would be about evenly divided above and below but, differing by more than 5 db from the average.

The losses of intertoll trunks in the telephone plant are now being assigned in such a way that, even allowing for the probability of adverse variations in actual trunk loss, return loss at the circuit terminal, and individual's tolerance to echo, the chance of a customer hearing objectionable echo is extremely small. This means that, despite the general endeavor to provide as low loss corrections as possible, designers of intertoll trunks must consider a minimum loss below which it is not safe to go without increasing the probability of objectionable echo conditions.

In the early days of long distance telephony, relatively heavily loaded lines were used extensively. This made the velocity of transmission low – in the order of 10,000 miles per second as compared with about 186,000 miles per second for the speed of light, or radio transmission. Round-trip delay times were therefore large on toll trunks of even medium length and echo was a serious limitation on the minimum loss which could be used.

This condition, in combination with the continual effort to provide better transmission, led to the invention of the echo suppressor. The principle of this voice-operated device that suppresses transmission in one direction on a four-wire circuit whenever speech is being transmitted in the other direction, is illustrated symbolically in Figure 4. As shown, the four-wire circuit transmits speech from the two-wire line at the west terminal, through the four-wire terminating set and along the upper path to the east terminating set and to the east two-wire line. From east to west, speech is transmitted by the lower path. When a person at the west end of the circuit is talking, a small part of his speech energy enters the west-to-east amplifier-rectifier bridged across the upper transmission path. Here the talker's speech energy is converted to direct current which is used to suppress transmission in the east-to-west direction. The effect is the same as if a relay had short circuited the lower transmission path. As a result, any reflections occurring at the east terminal cannot get back to the talker at the west terminal where they would be heard as echoes.

The use of echo suppressors made it possible to operate long toll trunks at much lower losses than would otherwise have been permissible. Echo suppressors are not, however, a cure-all for echo problems on all trunks; first, there is their cost. But probably more important is the fact that several echo suppressors on a built-up connection, where individual trunks are connected in tandem, can cause a condition known as "lockout." Lockout occurs when both directions of transmission are short circuited as a result of the simultaneous operations of two echo suppressors located a considerable distance apart on a long built-up connection. In this condition both customers are talking but neither one can hear the other. This effect of lockout is mitigated by a differential feature built into the echo suppressors that enables the louder of two talkers to take control. However, a finite time is required for one of the talkers to take control, and sometimes

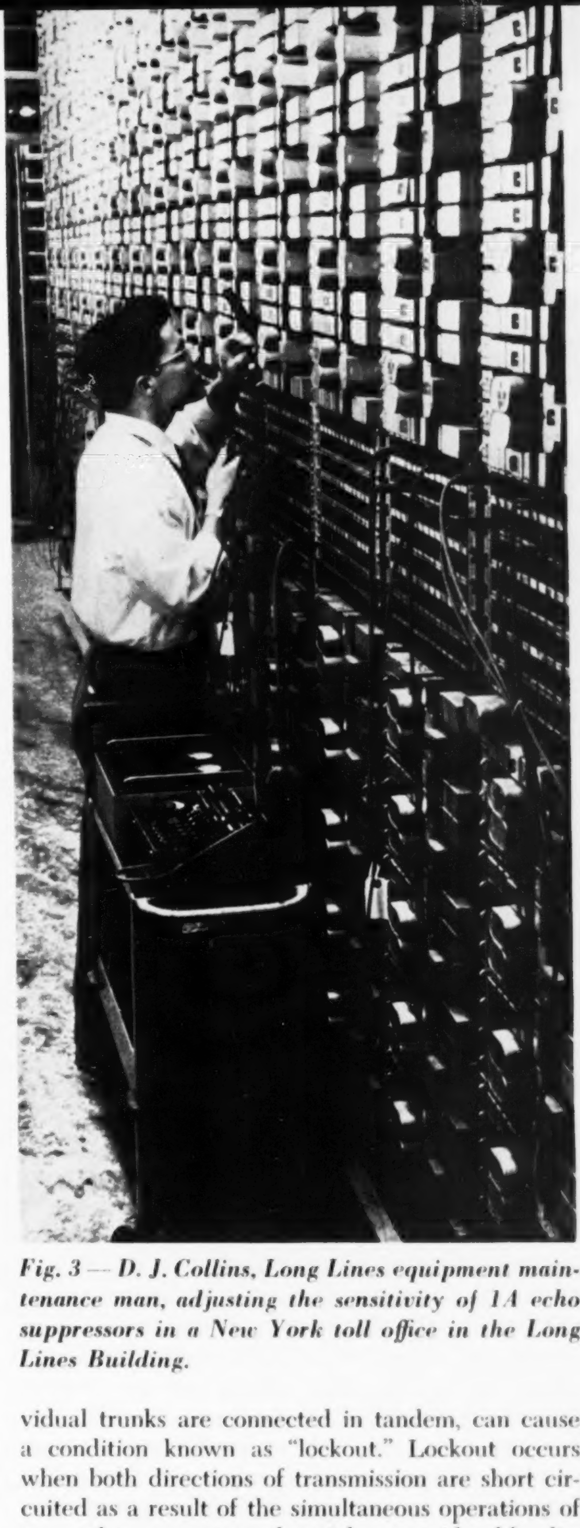


Fig. 3 — D. J. Collins, Long Lines equipment maintenance man, adjusting the sensitivity of 1A echo suppressors in a New York toll office in the Long Lines Building.

syllables or even words may be lost. Thus, the use of echo suppressors has been restricted by the fact that lockout and other difficulties can occur when a number of units are used in tandem.

In the present telephone plant, high velocity carrier or microwave radio transmission is used on practically all long distance trunks, and their use is being extended to a large portion of the medium and short trunks as well. Since the speed of carrier and radio transmission is usually in excess of 100,000 miles per second, round-trip delay times on today's telephone calls are generally much less than they were in the past. As the use of carrier and microwave systems increases, the trend is toward still shorter delay times, and this factor acts to reduce the importance of echoes. However, the need for lower intertoll trunk losses, brought about by the increasing use of nationwide machine switching, continues to make echo the principal limitation in trunk design. Shorter delays coupled with the need for lower transmission losses simply mean that a lower part of the curve that is shown in Figure 2 becomes the critical area.

In this regard, lower intertoll trunk losses are necessary with nationwide machine switching because of its automatic alternate-routing feature. In addition, built-up connections of several trunks in tandem will occur more frequently than with manual switching. Hence, if the individual trunk losses were not lowered, the average transmission quality would be impaired. Because of these lower losses, the shorter delays obtained by the use of carrier systems will not entirely eliminate the need for echo suppressors. Under the present toll switching plan, it seems that echo suppressors can be assigned sparingly in such a way as to minimize the probability of lockout occurring. But as the trend to lower-loss circuits continues, and as the switching plant is expanded, the search for improved methods of echo control must go on.

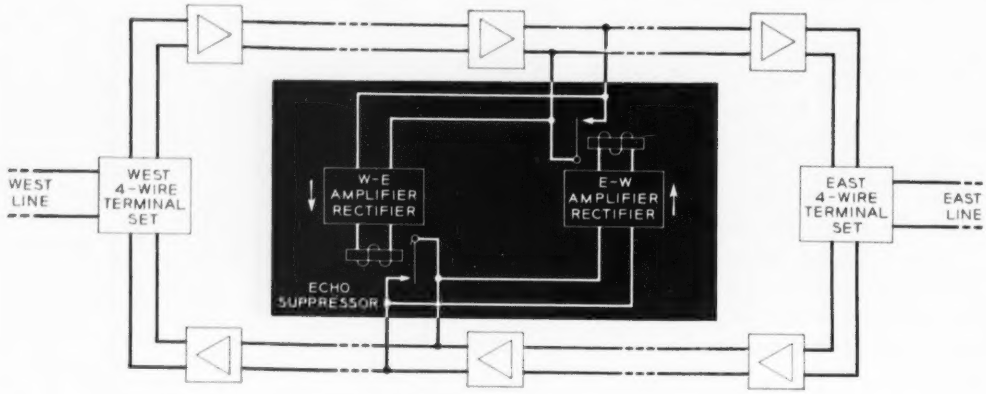


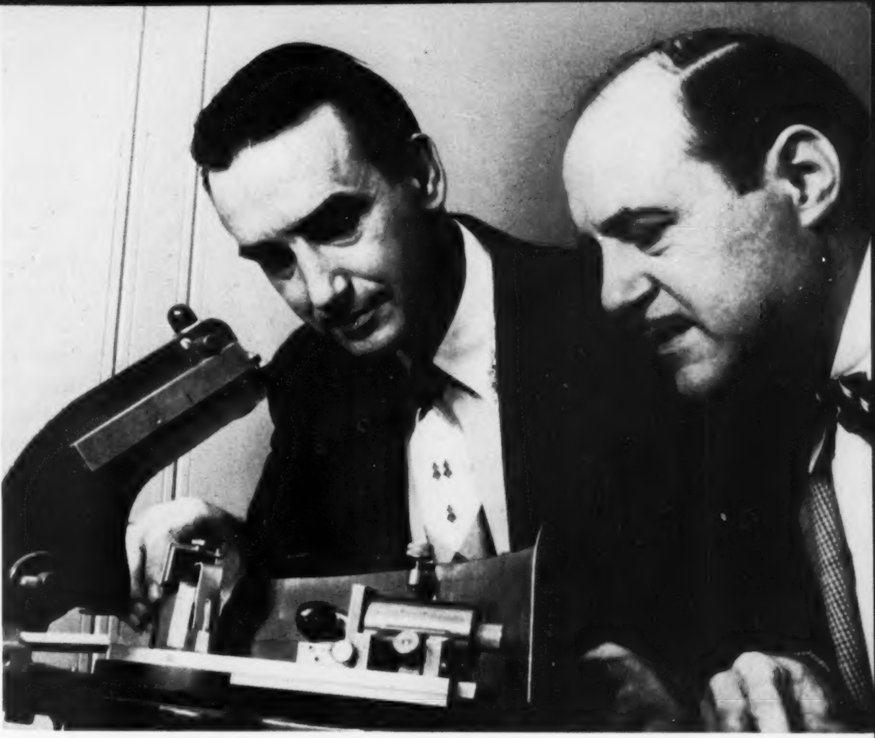
Fig. 4 — Schematic of the four-wire echo suppressor principle.

THE AUTHOR

George M. Phillips joined the Laboratories in 1930 and during the next several years was concerned with quartz-crystal cutting. In 1936 he joined the Transmission Development Department, as a member of the noise and crosstalk prevention group. Mr. Phillips continued in this assignment until World War II, when he became concerned with a Signal Corps project. After the war, he helped develop microwave testing equipment and in 1948 he joined Transmission Engineering, where he has been working with voice-frequency toll transmission problems. Mr. Phillips received a B.E.E. degree at Cooper Union in 1938 and has attended Brooklyn Polytechnic Institute.

Semiconductors: Characteristics and Devices

G. L. PEARSON *Transistor Physics*



The great interest shown in the transistor should not obscure the fact that a wide variety of semiconducting devices is being investigated at Bell Telephone Laboratories. Many of these have already found important uses in the Bell System, and new ones show commercial possibilities. G. L. Pearson, co-inventor with D. M. Chapin and C. S. Fuller of the Bell solar battery, here discusses the principal semiconducting materials and some of the devices they have made possible.

Interest in semiconducting materials and devices has increased markedly since the announcement of the transistor by Bell Laboratories in 1948. Germanium, in particular, has been investigated very thoroughly and a fairly complete story is now known on this material. Prior to the transistor, however, a large number of semiconducting devices were being built, and this program has expanded rapidly as a result of recently acquired knowledge.

One class of such devices consists of rectifiers, detectors and modulators made of such widely varying semiconductors as copper oxide, selenium, germanium and silicon. Another is the thermistor which is usually made of semiconducting metal oxides such as nickel, manganese, cobalt or titanium. A third class which should be mentioned is the silicon carbide varistor. Figure 1 shows from left to right an n-p-n junction transistor fabricated from germanium, a p-n junction diode fabricated from silicon, a thermistor made from a mixture of metal oxides, and a silicon carbide varistor. Figure 2 is a photograph of these semiconducting materials and from left to right shows a single-crystal ingot of germanium, a single-crystal ingot of silicon, a powder mixture of nickel, manganese and cobalt oxides, and a multicrystalline silicon carbide ingot.

Semiconductors, as the name implies, are a class of materials which have an electrical conductivity between insulators and metals and fall in the range 10^{-3} to 10^{3} (ohm-centimeters)$^{-1}$ near room temperature. In comparison, the conductivity of typical metals in this temperature range is around 10^{5} and that of insulators between 10^{-6} and 10^{-15} (ohm-centimeters)$^{-1}$ or lower. The electrical conductivity of semiconductors and many insulators increases rapidly with rise in temperature, while that of metals decreases relatively slowly. Semiconductors may be classified on the basis of their current-carriers into electronic, ionic and mixed conductors. In ionic and mixed conductors, ions are transported through the solid, thus changing the composition of the material. Since this leads to unstable characteristics, only those substances in which the current is carried solely by electrons will be discussed.

As early as 1900 P. Drude suggested that the high electrical conductivity of metals was due to the large number of so-called free electrons. These electrons are free in the sense that under the action of an electric field they move through the crystal lattice, thus carrying a current. Their number is in

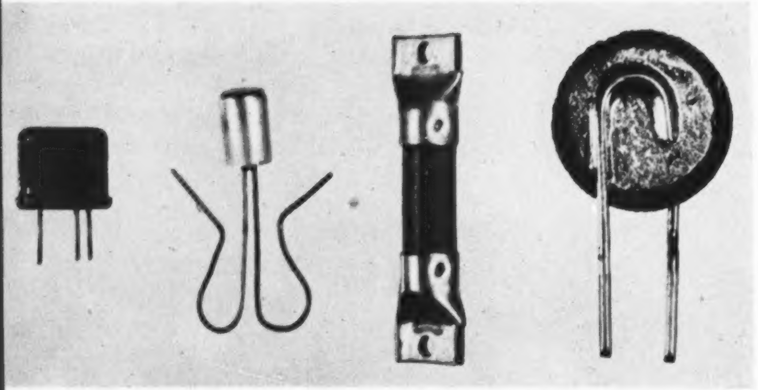
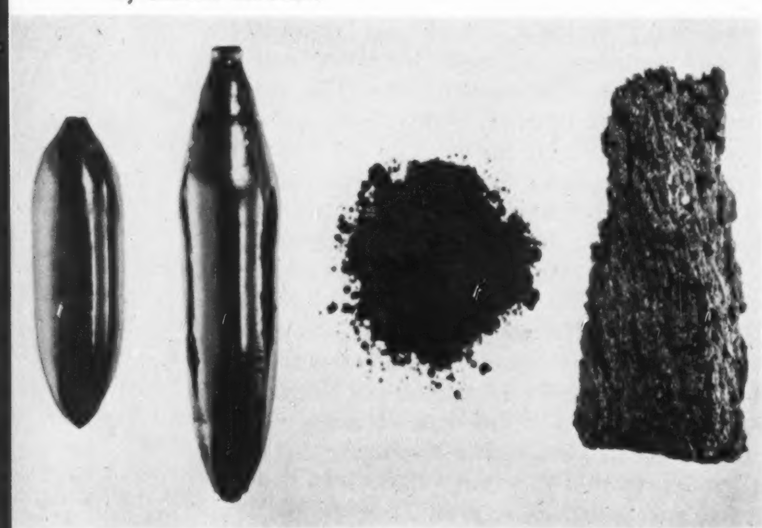


Fig. 1 — Left to right: a germanium n-p-n junction transistor, a silicon p-n junction diode, a thermistor, and a silicon carbide varistor.

the order of one per atom or approximately 10^{22} per cubic centimeter in most metals, and this density does not change appreciably with temperature. In the modern theory of semiconductors as proposed by A. H. Wilson around 1930, it is shown that most of the electrons in these substances are bound to their respective atoms, thus leaving only a small fraction of the electrons (1 per 10^3 to 10^9 atoms) free to conduct current. Furthermore, the number of free electrons increases with increase in temperature, thus accounting for the high negative temperature coefficient of resistance in semiconductors.

This increase in electrical conductivity with increase in temperature has been utilized in thermistors (a contraction of the words "thermal resistors"). This class of devices*, which originated at Bell Telephone Laboratories around 1940, is made from a mixture of metallic oxides. The desired proportions of oxide powders are mixed with a binder and fired at a high temperature to produce a solid body to which leads are attached. These devices have extremely stable characteristics and change their resistance only under the influence of heat. They fall into the category of "ohmic" devices, or those obeying Ohm's law that voltage is proportional to current and resistance. They are to be contrasted with other semiconducting devices exhibiting non-ohmic properties. The characteristics of two commonly used thermistor materials are given in Table I. Upwards of fifty different thermistors have been coded, and over ten million units are now in operation in the Bell System. Some of the more important applications include automatic volume regulators on carrier systems, surge eliminators in PBX stations, temperature compensators, and temperature regulators.

Fig. 2 — Left to right: a single-crystal ingot of germanium, a single-crystal ingot of silicon, a powder mixture of nickel, manganese and cobalt oxides, and a multicrystalline ingot of silicon carbide.



The electrical characteristics of semiconductors may be better understood by considering their chemical behavior. The chemical properties of an atom are determined by the valence or weakly bound electrons in its outermost incomplete shell. In an insulator all of these valence electrons are tied up in the chemical bonds which hold the crystal together so that we have no free electrons for conducting electricity. Diamond is an example of a good insulator; its four valence electrons are tightly bound so that they cannot move under the influence of an electrical field. Although the semiconductors germanium and silicon have a tetravalent diamond-type lattice, their valence electrons are not so tightly bound, and they may be freed to conduct merely by the thermal vibration of the lattice even at room temperature or by the energy imparted by photons of light. The energy necessary to free a bound electron in diamond is 11×10^{-12} ergs (7 electron volts), while that for silicon is only 1.8×10^{-12} ergs (1.1 electron volts), and that for germanium only 1.2×10^{-12} ergs (.75 electron volts). Once freed, the electron drifts toward the anode if an external electric field is applied to the crystal. We call this conduction mechanism n-type since negative charges (electrons) carry the current.

There is a second conduction mechanism simultaneously present which we must also consider. When the electron is broken from its bond position

* Record, *December*, 1940, *page* 106.

and turned into a conduction electron, a vacant bond site or "hole" is left behind. An electron from an adjacent bond may move over to fill this vacancy and thereby shift the hole to a new position. Since this process can go on indefinitely, a free hole wanders through the crystal almost as easily as a free electron. Under the influence of an external field, holes drift in the opposite direction to the electrons. We call conduction by holes p-type, since the holes act like positive charges. This dual role of conduction by electrons (n-type) and conduction by holes (p-type) is fundamental in the new semiconductor electronics outlined by W. Shockley of Bell Telephone Laboratories in his book* published in 1950.

In the above discussion, we have considered only pure (intrinsic) semiconducting crystals in which electrons and holes are always produced in equal numbers under the influence of heat and light. By adding certain kinds of impurity atoms to the crystal, one can produce a crystal which conducts almost entirely by electrons (n-type) or almost entirely by holes (p-type).

TABLE I — PROPERTIES OF THERMISTOR MATERIALS

Material	*No. 1*	*No. 2*
Composition	(NiO, Mn_3O_4)	(NiO, Mn_3O_4, Co_2O_3)
Resistivity ρ at 25°C	2200 ohm-cm	285 ohm-cm
Tem. Coeff. α at 25°C	4.4	3.8
ρ 0°C/ρ 200°C	500	220

Consider a germanium crystal in which one of the germanium atoms has been replaced by an atom from the fifth column of the periodic table, for example phosphorus. Now phosphorus has five valence electrons, one more than germanium, so that after bonding to the four neighboring germanium atoms one valence electron is left over. This electron is very loosely bound (activation energy $= 1.6 \times 10^{-14}$ ergs $= 0.01$ electron volts) and is freed by thermal vibration at temperatures as low as that of liquid nitrogen. When this electron wanders off, the phosphorus atom left behind is positively charged. When an electric field is applied to a germanium crystal to which many phosphorus atoms have been added, only n-type conduction takes place, since no holes are formed in the ionization process; and the positively charged phosphorus ions are tightly bound in the germanium lattice.

If we had used impurity atoms from the third column of the periodic table, such as boron, we would have had only p-type conductivity. This comes about because boron has only three valence electrons, so that a hole is left in the valence bond structure. This hole is likewise loosely bound and conducts freely while the negatively charged boron atom remains fixed. If both phosphorus and boron impurity atoms are added simultaneously, the conductivity type is that of the more abundant impurity, and the number of free carriers is equal to their difference.

When an external electric field is applied to a semiconducting crystal, the free carrier speed is directly proportional to the field strength. The speed in cm/sec at a field of one volt/cm is called the mobility. The mobility of electrons is greater than

Fig. 3 — W. F. Flood placing section of ingot in position for sawing out germanium wafer.

that of holes, and both travel faster in germanium than in silicon.

There are 4.42×10^{22} atoms per cc in an intrinsic germanium crystal, and at room temperature the electrical conductivity due to ionized electron-hole pairs is only 0.021 (ohm-cm)$^{-1}$. The addition of only one phosphorus (or boron) atom per billion germanium atoms produces a detectable increase in conductivity and makes the crystal n-type (or p-type). One of the most important contributions to modern semiconductor technology has been the development of methods, by our chemists and metallurgists, for purifying germanium and silicon to such high standards. Of no less importance has been the development of methods for producing single crystals of these elements containing con-

* *Electrons and Holes in Semiconductors,* D. Van Nostrand Co., Inc., New York, New York.

Fig. 4 — W. L. Feldmann using micromanipulator to place gold and aluminum on silicon cube by alloying technique.

trolled amounts of given impurities. Some of the pertinent constants of germanium and silicon are given in Table II.

When a metal point is placed against an impurity semiconductor, the combination has a nonlinear current versus voltage characteristic and acts as a rectifier. That is, such a device is non-ohmic in character. This class of device is called a point-contact diode. For an n-type sample, the current is large when the semiconductor is made negative and the metal point is positive, but it is small when these polarities are reversed. For a p-type sample, the sign of the effect is reversed so that the current is large when the semiconductor is positive.

The operation of the diode may be explained with the aid of our chemical bond picture in an impurity semiconductor. Suppose we place a metal point against a germanium crystal containing phosphorus (n-type). The extra valence electrons are thermally excited, leaving the phosphorus atoms positively charged. The electrons in the contact area drift away, thus leaving next to the point a positively charged barrier layer from 10^{-6} to 10^{-4} centimeters in thickness. This barrier layer is a region of high resistivity, so that when an external voltage is applied between the metal point and the semiconductor, almost the entire drop is across this layer. If the external voltage is poled to make the semiconductor positive, the barrier layer is increased in thickness and the resistance goes up. If the semiconductor is made negative, the semiconductor layer becomes thinner and disappears entirely for sufficiently high voltage. This is the direction of low resistance and high current. The case of a p-type semiconductor in contact with a metal is analogous, excepting that the free carriers are holes and the external voltage must be reversed. Silicon point-contact diodes were developed during World War II and were used in very large numbers as radar detectors. Since the war, germanium point-contact diodes have been manufactured in still larger numbers to be used as circuit elements in an ever-expanding electronics industry.

The point-contact transistor, discovered by J. Bardeen and W. H. Brattain, was an outgrowth of the semiconductor research program at Bell Telephone Laboratories and consists of two closely spaced metal point contacts pressed against a wafer of n-type germanium. The one metal point (the emitter) is biased in the forward direction – that is, point positive – and the other metal point (the collector) is biased in the reverse direction – that is, with point negative. A large-area ohmic electrode is attached to the semiconductor and serves as a common base. At zero emitter current, the collector has a high impedance to the normally present electrons, but with flow of emitter current, holes are generated in the neighborhood of the emitter. These holes are drawn to the negatively biased collector, and the device is an amplifier showing gains in current, voltage and power.

Still another type of non-ohmic semiconducting device is the silicon carbide varistor* (for "variable resistor"). Silicon carbide granules are mixed with graphite and ball clay and then pressed into thin wafers. These wafers are fired in an appropriate reducing atmosphere until a refractory body is formed. After electrodes have been attached to the two faces of the wafer, it is found that the electrical characteristics over a large range in voltage V are given by the relation $I = KV^n$ where I is the current, K a constant, and the exponent n is a constant having values between 3 and 7, depending upon the processing and voltage requirements. Although the operation of this device is not completely understood, its non-ohmic nature is certainly determined by the matrix of rectifying contacts between the silicon carbide granules which are embedded in the insulating ball clay. Although silicon carbide varistors were first made around 1930, they were not used extensively in the Bell

* RECORD, *October*, 1940, *page* 46.

System until 1951, when they became components of the 500-type telephone set, serving as equalizers.

The semiconducting materials discussed above are uniform in composition throughout each single crystal—that is, they are entirely n-type or entirely p-type. We now turn to materials in which one part of the single crystal is deliberately made n-type and another p-type. The region of greatest interest to us is the boundary between the two conductivity types which we call a p-n junction. The fact that a p-n junction acts as an almost perfect rectifier as well as an almost perfect emitter makes it the most important single element in recent semiconductor technology. Following Shockley's fundamental development of the theory of the p-n junction, as published in 1949, we have passed such important milestones as (1) the germanium n-p-n and p-n-p transistors; (2) the germanium p-n junction phototransistor; (3) the germanium p-n junction power rectifier and the silicon alloy p-n junction diode; (4) the unipolar and p-n-i-p transistors; and (5) the recently announced silicon p-n junction solar battery, power rectifier, and lightning protector.[*] Since the properties of p-n junctions have been covered quite thoroughly in a previous article[†] on semiconducting devices, nothing further will be said here on this very important subject.

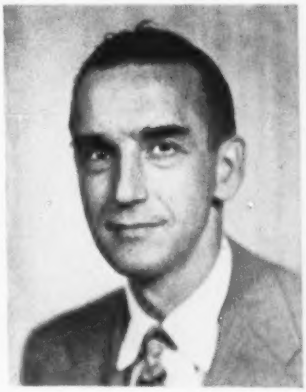
An entirely new set of semiconducting materials has been of special interest in recent years. This class consists of compounds containing equal numbers of atoms of elements from the third and fifth columns of the periodic table. Although the individual elements are metallic and of different crystal structure, when formed into stoichiometric compounds (in this case, compounds having equal numbers of the constituent atoms) they form a diamond-type lattice and exhibit semiconducting properties. These intermetallic compounds will be the subject of a future Record article. The one most thoroughly investigated to date is indium antimonide (InSb), although gallium antimonide (GaSb), aluminum antimonide (AlSb), gallium phosphide (GaP) and indium phosphide (InP) have also been studied. Although no useful devices have as yet been constructed, the preliminary results are encouraging and may well become of commercial importance after further development.

TABLE II – PROPERTIES OF GERMANIUM AND SILICON

	Ge	Si
Melting Point	936°C	1420°C
Density	5.323 gm/cm^3	2.328 gm/cm^3
Thermal Expansion Coeff. (25°C)	6.1 X 10^{-6}/°C	4.2 X 10^{-6}/°C
Thermal Conductivity (25°C)	0.14 cal/sec cm°C	0.20 cal/sec cm°C
Specific Heat (0-100°C)	0.074 cal/gm°C	0.181 cal/gm°C
Atomic weight	72.60	28.08
Lattice constant	5.657 X 10^{-8}cm	5.431 X 10^{-8}cm
Atoms/cc	4.42 X 10^{22}	5.22 X 10^{22}
Volume Compressibility	1.3 X 10^{-12} cm^2/dyne	0.98 cm^2/dyne
Dielectric constant	16	12
Covalent bond ionization energy	0.75 electron volts	1.1 electron volts
Impurity atom ionization energy	$\approx$0.01 electron volts	$\approx$0.04 electron volts
Intrinsic resistivity at 300°K	47 ohm cm	63,600 ohm cm
Electron mobility at 300°K	3,600 cm^2/volt sec	1,260 cm^2/volt sec
Hole mobility at 300°K	1,700 cm^2/volt sec	500 cm^2/volt sec

[*] Record, *June*, 1954, *page* 232.
[†] Record, *June*, 1954, *page* 203.

THE AUTHOR



Gerald L. Pearson received A.B. (1926) and M.A. (1929) degrees in physics from Willamette and Stanford Universities, respectively. He became a member of the Laboratories Physical Research Department in 1929, spending his early years at the Laboratories on studies of noise in resistors, vacuum tubes and carbon microphones. Except for a brief period during World War II, when he was engaged in work on military projects, he has since concentrated on semiconductor research. In this field he has been concerned with thermistors, transistors, and more recently, silicon rectifiers which led to the invention of the solar battery.

This early picture of the Limon test plot suggests the dry, dust-bowl characteristics of the area.

Telephone Poles End 25-Year Test in Colorado

One of the Bell System's four outdoor test plots for timber products was closed down recently after the completion of 25 years of telephone pole "life tests." The one-acre plot, located at Limon, Colorado, was used by Bell Laboratories timber products engineers to determine the best methods of wood preservation for lodgepole pine and western red cedar, two types of poles economically practical in the Western states.

Limon was chosen as the site for the tests because of its location in a typically dry, "dust-bowl" climate noted for its severe exposure conditions, and because of its adobe-type soil. About 90 miles southeast of Denver and near the Kansas border, the area was selected in 1929 by G. Q. Lumsden, now timber products engineer at Murray Hill, and R. W. Lindsay, now vice president of the Mountain States Telephone and Telegraph Company, who was then outside plant engineer of that company.

The "vintage" of some of the 405 pole specimens (in left background) is shown by one of the cars used by the crew which put up the poles. The year was 1929.

Similar test plots are located in other climates. The largest in terms of pole specimens is at Chester, N. J., established in 1929; a 26-acre plot was opened in 1952 at Orange Park, Florida; and the oldest is a small plot at Gulfport, Mississippi, that was staked out in 1925.

As a result of the tests at Limon, the best wood preservative was found to be creosote or pentachlorophenol-petroleum. Also tested were greensalt, and several inorganic salts, including various mercury and copper compounds.

The full-length pressure impregnation treatment of lodgepole pine was found to be an engineering must, even in these dry areas, particularly because of wood-destroying fungi and the aerial termites common to the Southwest. Western red cedar used to be butt treated only but today this pole is preserved over its full length by submersion in long tanks containing first hot, then cold preservative.

Limon tests also proved that a certain timber disease, "red heart," stops its decaying action shortly after the tree is cut. This led to the use of many poles which would otherwise have been rejected because of a small amount of red heart decay.

Another test proved the reliability of glued joints in crossarms constructed of layers of Douglas fir and used in dry, dust-bowl areas. These laminated crossarms, from which knots and other imperfections are cut, are as strong as those made from a single timber.

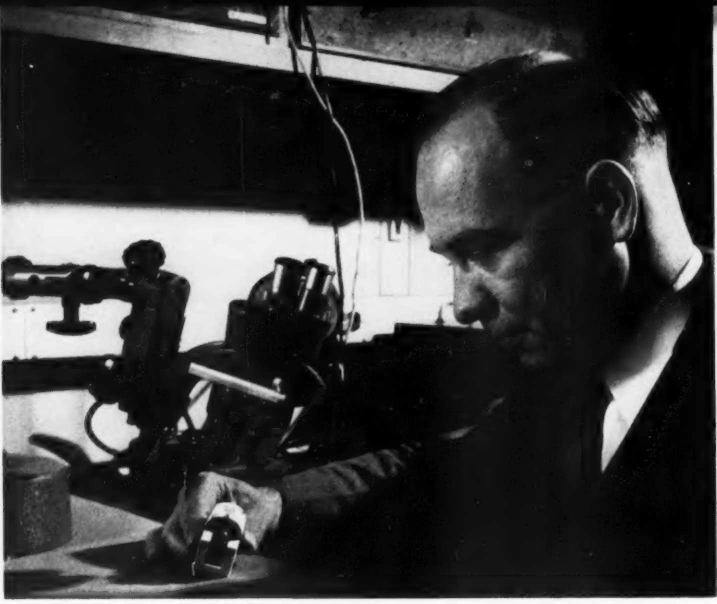
Forty-three of the 405 ten-foot pole lengths from Limon have been shipped to Murray Hill where they are now being cut, shredded, and analyzed to determine how much of the wood preservative has been retained in the 25 years. By determining the extent of evaporation at Limon, the serviceable life of the properly treated pole can be accurately predicted.

One of the earliest poles begins its test. Pictured here are (left to right) R. H. Colley of the Laboratories (now retired), Roger Holbrook of Mountain States, H. R. Cordes of W. E., G. Q. Lumsden, now Bell Laboratories Timber Products Engineer, Elmer Coyer of Mountain States and an unidentified Mountain States man.

Poles from Lima were shipped to Murray Hill and sawed up in preparation for a chemical analysis of the remaining preservative. G. Q. Lumsden watches Eric Sundstrom cut a pole into discs.

After the discs are ground into shreds, the creosote preservative is extracted from the wood by a "percolation" process. Next step will be the analysis of the creosote that was in the pole.

Precision Transformers for the L3 System



C. W. THULIN *Transmission Development*

A completely new transformer of unusual design is one of many new components developed for the L3 coaxial carrier system. In this transformer, windings are precisely formed in ceramic cylinders by cutting threads and filling them with copper. The resulting transformer maintains its physical dimensions with time and temperature changes, and its electrical characteristics are more precise than those of conventional types.

To obtain the transmission system performance that is now being realized in the L3 coaxial system, it was necessary that the component parts be precisely designed and their manufacture precisely controlled. This system is engineered to maintain an economic balance among various factors, including the precision of components in the transmission path, the complexity of the required equalization, the amount of information the system transmits, and the distance over which this information is transmitted. This balance is realized in the L3 coaxial system on circuits up to four thousand miles long, and over a frequency band extending from approximately 0.3 to 8.3 megacycles.

On such an L3 route, the total cable loss would be about 46,000 db, and this loss would be offset by over one thousand repeaters located at four-mile intervals. Each of these repeaters includes two line-amplifier transformers, one located at the input and the other at the output of the amplifier. Therefore, more than two thousand of these transformers would be used in each direction on a single transcontinental system.

Transformer operation at carrier frequencies is affected to a large extent by internal parasitics, such as leakage inductances and distributed capacitances. The L3 line-amplifier transformer makes use of these parasitics to provide an accurate transmission characteristic that compensates in part for the increase in cable loss with frequency. Some of the most important of these parasitics are illustrated in Figure 1. Since more than two thousand of these transformers may be used in tandem, the parasitics must be reproduced and controlled to an extraordinarily high degree. As a result, new and novel techniques in design and construction had to be employed, and hence the appearance of the trans-

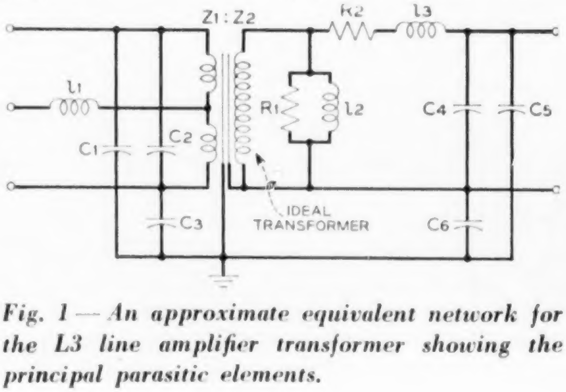


Fig. 1 — An approximate equivalent network for the L3 line amplifier transformer showing the principal parasitic elements.

former shown in the headpiece is quite different from that of conventional types.

In addition to the normal function of providing voltage or current gain, these transformers perform three principal tasks in a repeater. First, the transformer operates as a hybrid coil and, with the aid of other components, provides a close impedance match to the cable. Second, the parasitic inductances and capacitances are used to shape the transmission characteristic. Third, the transformer is used to isolate grounds in the repeater that would otherwise limit amplifier performance. To perform these tasks adequately, the transformer must operate outside the feedback circuit of the amplifier; thus repeater gain is sensitive to transformer variations. In minimizing temperature, aging, and initial variations, the new transformer design has yielded improvements in precision ranging from five-to-one up to one hundred-to-one over those previously obtainable.

To satisfy the various requirements imposed upon it, extensive use is made of ceramic materials in the construction of this transformer. As illustrated in Figure 2, a type of ceramic called steatite is used for the transformer casing, and the ceramic core material is high permeability manganese-zinc ferrite. In addition, the ceramic used for the winding forms, shown in Figures 3 and 4, consists of fused quartz or glass with a high silica content. These materials, in addition to having good electrical properties and low temperature coefficients, can be held to very close dimensional tolerances by means of recently developed techniques. This close control of the mechanical dimensions insures the electrical precision required.

Since the principal contributions to the transformer parasitics are in the winding assembly, precision in the forming of this unit is of prime importance. As shown in Figures 3 and 4, this assembly consists of three concentric ceramic forms made from fused quartz or special glass. The in-

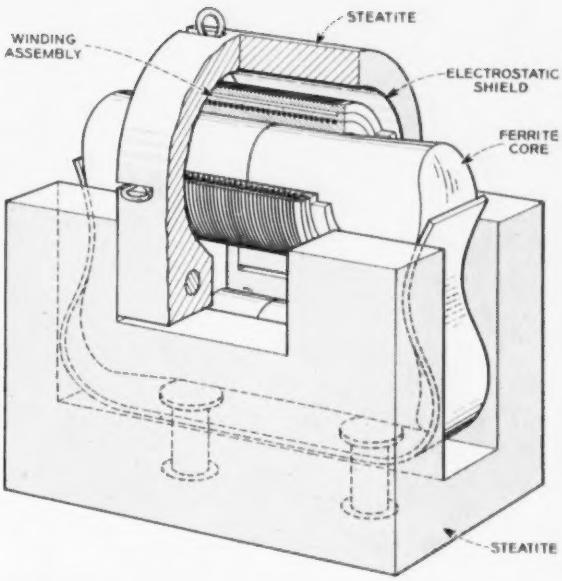


Fig. 2 — Cross section showing construction of the transformer using ferrite and steatite.

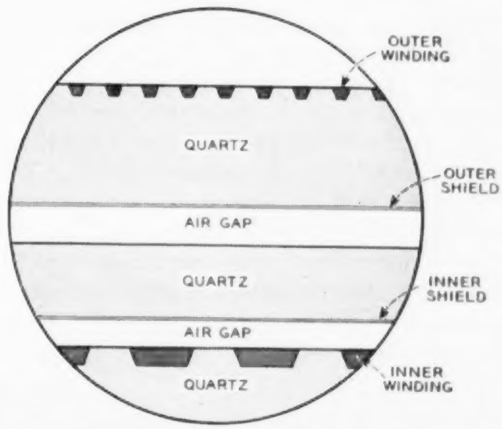


Fig. 3 — Cross section view of the transformer winding pile-up using fused quartz.

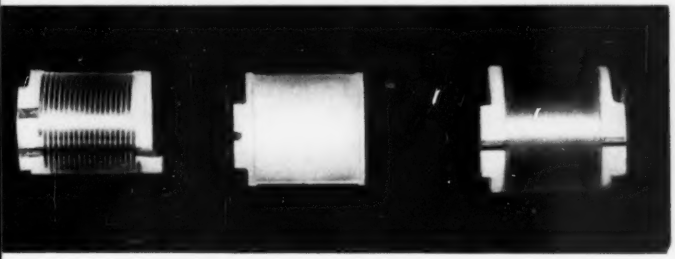


Fig. 4 — Concentric forms constituting the winding pile-up made from fused quartz or special glass.

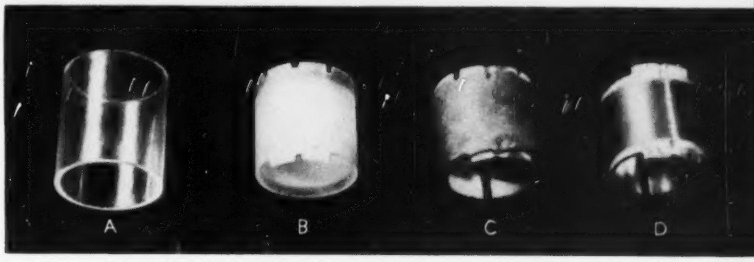


Fig. 5 — Steps in manufacture of the outer winding pile-up form of the precision transformer.

Fig. 6 — W. L. Brune, who introduced the L3 transformer design into production, measuring the transmission characteristics of a completed unit.

nermost of these three forms contains the transformer primary windings which are applied as a pair of helices. The middle form supports an inner electrostatic shield that isolates the amplifier feedback signal from the transformer primary windings. The outer form contains the secondary windings and the outer electrostatic shield. This outer shield, extending to the casing's inner surface, minimizes the parasitic capacitance labeled c_5 in Figure 1.

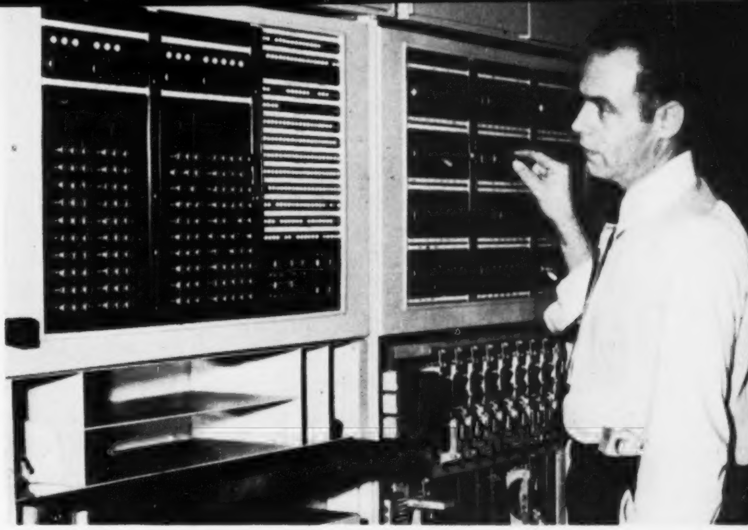
The method of construction used for these forms is illustrated in Figure 5. The tubing at "A" on the left of this figure is made of transparent fused quartz. This tubing is first processed with diamond tools to obtain concentric inner and outer surfaces held to a tolerance of 0.0005 inch. A thread 0.005 inch deep with a pitch of 88 turns per inch is then cut into the form, and provisions are made for the necessary electrical connections. After these operations are completed, the form appears as shown at B in Figure 5. This form is then sprayed with a mixture of finely ground glass and silver, and the unit is heated to the point where a bond is formed when the glass melts and fuses to the quartz. The resulting silver surface is then electroplated with copper until the machined threads are filled. At this point the form appears as shown at C. Any excess silver and copper is removed by grinding, and the finished form appears as at D. The winding then has the same dimensional stability as the quartz. Although the initial cost of these transformers is higher than that of conventional types, this expense involved is far outweighed by the savings they make possible in equalizing the L3 coaxial cable.

The success of this design is due in considerable measure to the co-operation of the ceramics and electroplating groups at Bell Telephone Laboratories, and the engineering and production groups at the Haverhill Plant of the Western Electric Company. Special techniques have been developed, and machines, jigs, and fixtures designed or adapted to meet the needs of this unusual transformer design. For these reasons, it has been possible to achieve the high degree of precision in this transformer using semi-automatic machinery on a production basis.

THE AUTHOR

Charles W. Thulin received his B.S. degree in Electrical Engineering at Worcester Polytechnic Institute in 1939 and his M.S. in Electrical Engineering at the same institution in 1941. Mr. Thulin was a member of the Laboratories technical staff for several months in 1941. He returned to Worcester Polytechnic Institute as an instructor until 1942 when he came back to the Laboratories. Until 1946 he worked with the design and development of radar for the Armed Forces. Since then he has been concerned with the design and development of wideband transformers for use in the telephone plant, particularly for television and coaxial systems. In 1951 he was assigned to a government project and he has since been concerned with high voltage pulse transformers and magnetic modulators. He is a member of Tau Beta Pi and Sigma Xi and a senior member of the Institute of Radio Engineers.

Senders for the 4A Toll System



M. E. ESTERNAUX

Switching Systems Development II

An important function in common-control automatic telephone systems is storing received digits and then pulsing them forward to the next office as required. This function is performed by a device called a sender; in the 4A toll crossbar system, senders also perform other functions necessary for nationwide dialing. These include sending forward varying numbers of digits, deleting digits, manufacturing new digits, and converting code digits into other digits.

Like other Bell System crossbar telephone systems, 4A toll crossbar utilizes common-control circuits to establish a connection through an office. One of these circuits, known as a sender, receives and stores the addressed telephone number and regenerates the digits for transmission to the next office. This storing of received digits enables the other common-control circuits to perform their functions, such as translating, searching for idle paths, and establishing a connection forward.

In addition to the basic functions of receiving, storing, and transmitting digits, accomplished in other systems by similar circuits, 4A senders are required to complete a variety of other tasks necessary for the implementation of the nationwide dialing plan. The highly diversified features of this plan required the development of two new types of incoming senders for 4A toll crossbar offices. One type, the "dial-pulse sender," receives digits in the form of dial pulses; the other, the "multi-frequency-pulse sender," receives them in the form of voice-frequency tones. Except for minor differences, both types of senders then perform all their other functions in the same manner.

The primary objective of the 4A toll crossbar system development was to permit operators, and eventually customers, to dial calls directly to telephones in any part of this country and Canada. As has been stated in previous articles,* one of the first steps in realizing this objective was to divide the United States and Canada into telephone numbering areas. Each area is identified by a distinctive three-digit code that does not conflict with any other area or local central-office code. A customer's regular number, consisting of a local office code (ABX) followed by numerals, is preceded by an area code (XOX or X1X) for inter-area dialing purposes. An "X" here represents any digit 2 to 9. Thus, the complete number will consist of ten digits—XOX-ABX-1234—except when a party letter or number above 9,999 increases it to eleven. This means that telephone number ABX-1234 is located in area XOX, and calls originating in other areas must first be directed to XOX through various toll offices.

Other necessary steps for nationwide dialing are to provide for such basic new features as: (1) automatic alternate routing of calls, (2) six-digit translation, (3) code conversion, and (4) the variable spilling forward of digits as needed. These features are made possible through the cooperative effort of the several common-control circuits,† including the two new senders.

An incoming call received by a 4A office may be routed to a local office in the same area – toll completing (TC), or to another toll office in any area

Above — J. C. Schoenenberger operates a key on the sender automatic test frame. Tests with this device, both automatic and manual, aid in maintaining sender performance.

* RECORD, *October*, 1953, *page* 369.

† RECORD, *December*, 1953, *page* 481.

– intertoll (IT). Regardless of whether the connection to be established is TC or IT, the call must first be directed to a sender by a sender link and link controller as in the earlier No. 4 toll crossbar offices.* After the incoming trunk is associated with a sender, and before any digits are received, the sender is furnished information called "incoming class" in the form of polarized and marginal signals from the trunk. This is used to assist other common-control equipment such as decoders, card translators, and markers in establishing a routing through the office, and to provide a proper count of different calls. It is also used by the dial-pulse sender to arrange for receiving either loop or simplex dial pulses.

Dial pulses, representing a digit, are received by a 4A dial-pulse sender as a series of one to ten open-circuit pulses. A faster means of signaling, called multifrequency pulsing, uses the simultaneous transmission of two voice-frequency tones for each digit. These tones are received by a 4A multifrequency-pulse sender which, with the aid of an electronic receiver, Figure 1, separates and detects the frequencies and identifies the numerical value of the received digit. In both types of senders, the digits are stored on relay registers.

As soon as the first three digits are received, and while others are still being registered, the sender

* Record, *April*, 1944, *page* 355 and *December*, 1945, *page* 466.

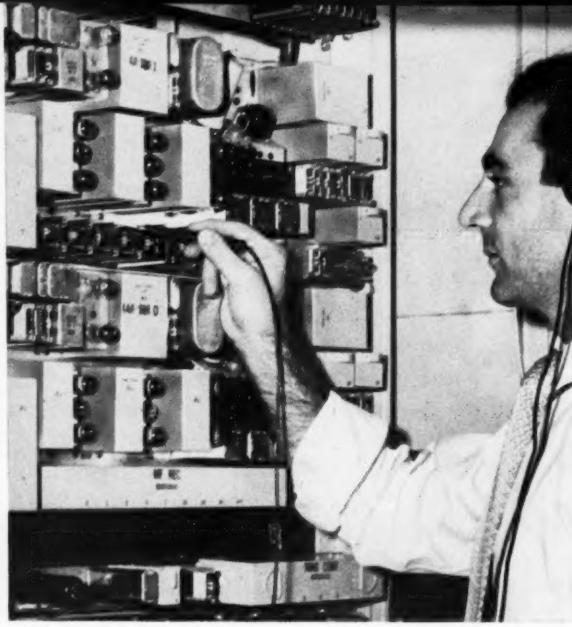


Fig. 1 — O. J. Russo tests a multifrequency receiver.

requests a translation from a card translator. If a complete translation can be made from these three digits, the sender is so advised, a marker is called in, and a connection to the next office is established. If more than three digits are needed for translation, the sender is requested to "come again" when the required number of digits are registered. When these digits are available, the sender again requests translation, is given the necessary instructions, and the call is established to the next office as before. The second request for translation is eliminated whenever all required code digits are available at the time the first translation is made.

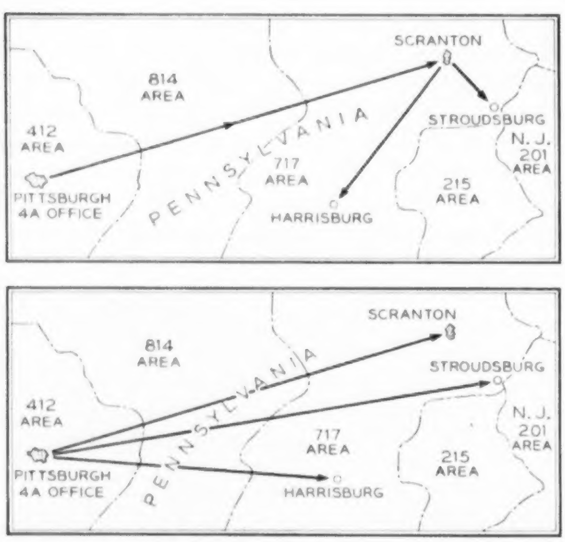


Fig. 2 — Six-digit translation permits the selection of direct trunks from Pittsburgh into area 717. Without this feature, all calls would have to be routed through Scranton.

Many of the calls handled by a 4A office can be completed by translating only the first three digits. However, whenever there is a choice of routes to another numbering area, the translator requires the first six digits, consisting of both the area code (XOX) and the local office code (ABX). A typical example of a six-digit translation is a call to a telephone in Harrisburg, Pa., located in the 717 area, and handled by the Pittsburgh 4A office located in the 412 area. This is illustrated in Figure 2. There is sufficient community of interest, telephone-wise, between Pittsburgh and various cities in the 717 area to warrant direct trunk-groups to Scranton, Harrisburg, and Stroudsburg. If only the three-digit area code 717 were available for translation in Pittsburgh, all calls for area 717 through Pittsburgh would have to be routed to one of these cities, such as Scranton, where they would then be switched to all other cities in the area. By translating the complete six-digit nationwide code at Pittsburgh, a direct trunk-group from Pittsburgh to Harrisburg is selected.

A few calls handled by the 4A system will have only four or five code digits for translation. Since the card translator is arranged to give a translation only when presented with either three or six digits, the sender must add enough digits to total six. Thus a sender, after presenting the first three digits to the card translator, is told to "come again" when senders are arranged to "speak" in most of the "languages" required by toll and local offices. Since only a few 4A offices need to communicate with local offices requiring the "panel call indicator" and "revertive" languages, these signaling methods were not included in the new incoming senders. For these calls, a No. 4 outgoing sender is used.

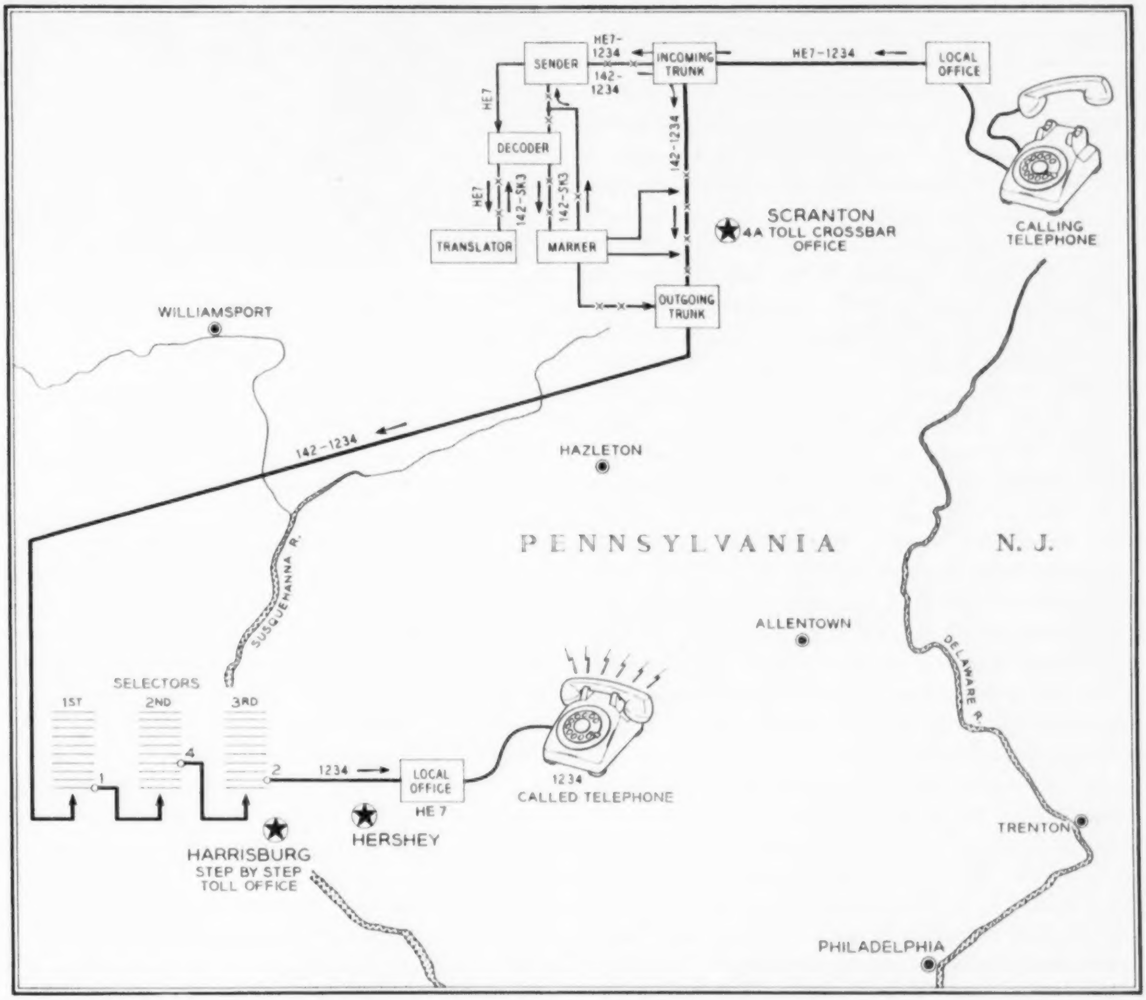


Fig. 3 — Code conversion of HE7, the nationwide central office code for Hershey, to 142 at Scranton permits the use of existing step-by-step equipment at Harrisburg.

four digits are available; it then disconnects from the translator, waits for the fourth digit to be registered, and manufactures zeros for the fifth and sixth digits before asking for another translation.

After the digits have been registered and translation of the code digits by the translator is completed, the sender is instructed as to what transmitting "language" is to be used and what digits are to be sent to the next office. The 4A incoming

Depending upon the routing established and instructions from the translator, a sender may send out, or "spill forward," either the same telephone number it receives or a different number. This new number may have just as many digits as the original or it may have more, less, or different digits. The features that permit such outpulsing, known as "variable spill" and "code conversion," are controlled by the card translator. When the next office

is a toll office not in the area to which the call is directed, all digits must be spilled forward and the sender receives a "no skip" signal from the translator. If the next office is a toll office in the area to which the call is directed, the sender receives a "skip 3" signal and the area code is deleted. All remaining digits, both local office code and numerals, are then spilled forward. On a seven- or eight-digit call, the "skip 3" signal is also furnished if the next office is a local office in the same area as the 4A office. In this case, the local office code is deleted and only the numerals are spilled forward. If the next office is a local office located in a different area, only the numerals are required to complete the call. For such a call the sender receives a "skip 6" signal and the entire six-digit code is deleted, only the numerals being spilled forward.

There are, of course, other conditions requiring the deletion of the first three or six digits. One of these occurs when the next office is a step-by-step toll office requiring one, two or three arbitrary directing digits. The translator instructs the sender to delete the proper number of digits and to add in their place the digits required by the step-by-step office. This adding or converting digits, called "code conversion," makes possible the routing of nationwide calls through existing step-by-step toll offices without resorting to extensive trunking rearrangements in these offices. An example of the use of this feature is a call to Hershey, Pa., reached via the Harrisburg, Pa., step-by-step toll office by the arbitrary code digits 142. Translation of HE7, the nationwide central office code for Hershey, results in the sender skipping the first three code digits and outpulsing the converted digits 142 before the numerals. This is shown in Figure 3.

If a 4A toll office has no direct route available to a local office in its own area, it may use a route through a toll office in a neighboring area and back again into its own area, as shown in Figure 4. Here, the three-digit local code HA9 is not sufficient to direct the toll office equipment in Philadelphia to establish a connection to the Haddonfield office in New Jersey. Translation of the three-digit local code in the Newark office causes the sender there to outpulse its own area code 201 before any other digits. Thus, instead of deleting digits, three digits are prefixed to those registered in the sender.

One feature of a 4A office, which reduces the time required to service a call, is known as "digit control." Since multifrequency incoming senders record their digits so fast, and since they know by the receipt of a distinctive signal that the number is completely registered, this feature applies only to dial-pulse incoming senders. The dial-pulse sender waits for three seconds after registering each digit, before deciding that it was the last one and proceeding with the call. However, translation of the code reveals the maximum number of digits required for the call, and this information is relayed to the sender. As soon as the sender receives the last required digit, the digit-control information cancels the three-second waiting time and the call progresses immediately. The signals supplied to the sender by the card translator are "0DG", "4DG", and "5DG", indicating that the number of digits to be expected is none, four, or five after the code digits. Certain calls directed to an operator with one, two, or three digits after the code digits are so infrequent that no provision for cancelling the three-second waiting time has been made for them.

Fig. 5 — The author makes a test on a multifrequency-pulse incoming sender.

Trunk-terminating equipment in some local offices requires a short time to restore to normal after completing a call, and before it can be used for another call. In the earlier No. 4 systems, the associated outgoing trunks were held "busy" until the distant office equipment was fully restored, preventing their selection by a marker until they were again normal. In the 4A system, a trunk is selected by the marker even though the distant office equipment is not fully restored. This, however, does not cause any reaction since, upon seizing a trunk, the marker starts a "trunk selected" timer in the sender. This timer delays the sender from proceeding until sufficient time has elapsed for the distant equipment to restore to normal.

This timer is also used when a call established to another office requires time for that office to prepare itself to receive the number. For such calls, the card translator tells the sender to "expect delay dial." The marker, when selecting this type of trunk, sends a seizure signal forward to the distant office. That office normally returns a "go" signal. However, as soon as it recognizes the seizure signal, it changes the "go" to a "stop." This stop signal continues until the distant office equipment is ready to receive digits and then the signal is again changed to "go." A "stop" signal always causes a sender to wait or to stop its pulsing of digits, and a "go" signal causes it to pulse digits forward.

This changing of signals from "go" to "stop" and then back to "go" could be very confusing to the sender. However, the "trunk selected" timer introduces a delay to prevent the sender from proceeding with the call until the signal is stabilized as either "stop" or "go." If the sender does not receive "expect delay dial" from the translator, it recognizes a "stop" signal from the distant office either as a trouble or as a simultaneous seizure from both ends of a two-way trunk. In this latter case, it sends a signal forward that may cause the distant office equipment to disconnect; if not, the sender will

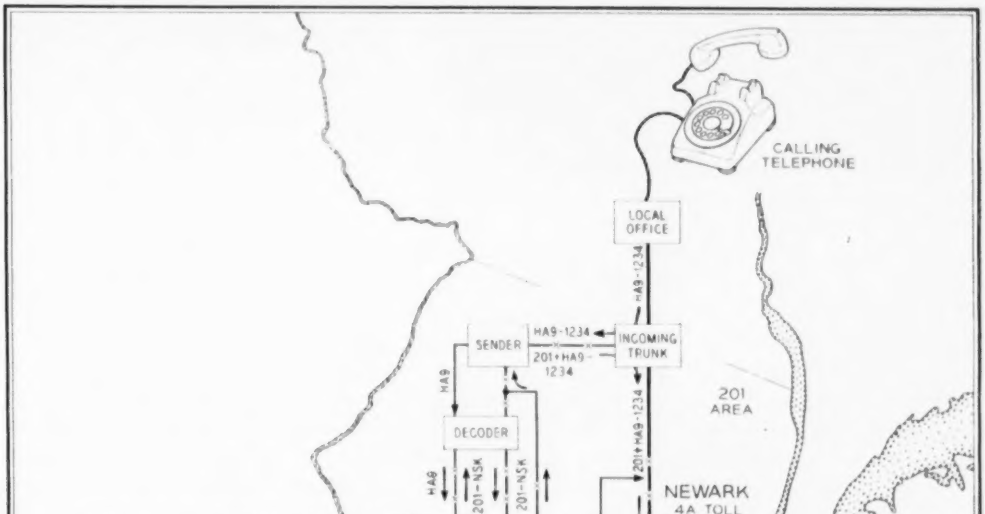


Fig. 4—A call through Newark to Haddonfield is routed through Philadelphia in another area. To direct the call back into area 201, the Newark 4A equipment must manufacture the digits 201 and prefix them to the number sent to Philadelphia.

"time out" and release. After a connection has been established, and one or more digits have been spilled forward, a "stop" signal may again be sent back to the sender. This "stop" signal means one of three things: (1) that the call is connected to the addressed telephone, (2) that all switching paths in the distant office are busy, or (3) that auxiliary equipment in the distant office requires a short delay between digits. For this last case, the translation informs the sender to "expect stop-go," and therefore to recognize the "stop" only as a delay, and not as completion of the call. When the distant equipment again signals "go," the sender resumes its spilling of digits. If, however, the translation does not indicate "expect stop-go," the sender recognizes a "stop" signal as a completion and will connect the incoming trunk through to the outgoing trunk and then release.

Some of the calls handled by the 4A system terminate in offices requiring a signal to start the local office equipment ringing the called customer's line. The translator directs the sender as to the type of signal required and when to apply it. After all digits are spilled forward, and the "start ringing" signal is sent ahead if required, the sender disconnects itself from the incoming trunk, restores to normal, and is then ready to receive another call.

In the 4A system, incoming senders can be delayed from completing calls by a shortage of idle equipment in another office, resulting from abnormal traffic or trouble conditions in that office. Normally, 4A senders wait from thirty to forty seconds before "timing out" and transferring the call to a reorder trunk. However, an "intersender overload timing" circuit reduces this waiting time to only three to eight seconds. When all senders in a group are busy, this shorter time automatically comes into operation and continues for about thirty seconds after at least one sender in the group becomes idle. When this feature is operative, a "timed-out" sender does not transfer the call to reorder, but transfers it instead to an overload announcement trunk. A recorded announcement then tells the caller that a delay is to be expected and how long the delay will last.

A 4A incoming sender that has received enough information to complete a call, yet fails to do so in the allotted time is called a "stuck sender." Visual and audible alarms are provided to indicate when a sender is stuck. A stuck sender causes a trouble record card to be punched, indicating how far the call progressed before the sender stuck. After the record is taken, the associated incoming trunk is connected to a reorder trunk and the sender is released. To facilitate corrective maintenance action, however, a key (one per office) at the maintenance center provides for the holding of up to a maximum of ten stuck senders. In this case a trouble record card is punched, but the call is not connected to reorder. Instead, the entire connection through the switches is held for tracing by maintenance personnel. By using the punched trouble cards the maintenance force can determine how far the call progressed and what equipment was involved in the failure. These trouble record cards and the testing of all sender functions by the automatic sender test frame, insure that a high standard of service is maintained.

THE AUTHOR

Max E. Esternaux entered the Bell System in 1921 via the New York Telephone Company. He remained with the New York Company until 1943 when he was granted a leave of absence to work with the Army and Air Force in the design and installation of message centers and communications systems in the Pacific Theater of Operations. Mr. Esternaux returned to the New York Company briefly in 1945 and was later temporarily assigned to Western Electric's Hawthorne Works. He has been with the Laboratories since 1946 and has been concerned with circuit designing and crossbar toll systems in connection with sender and marker design. He attended New York University and is a member of the Essay and Proof Society.

Varistor Measuring Techniques

R. R. BLAIR
Electronic Apparatus Development

The myriad uses of different types of varistors in the telephone plant, from the tiny bead types to large power rectifiers, have brought the study and development of such devices into prominence. Particularly in the study of small varistors, many extremely accurate measurements are necessary. In certain tests, a constant voltage must be maintained, yet sensitive microammeters must be protected from damage in case of accidental short-circuits. In other tests, measurements of current must be made in circuit elements having a resistance of two million megohms in one direction but only a few ohms in the other direction. Techniques and equipment necessary for such diverse measurements have been developed in the Laboratories.

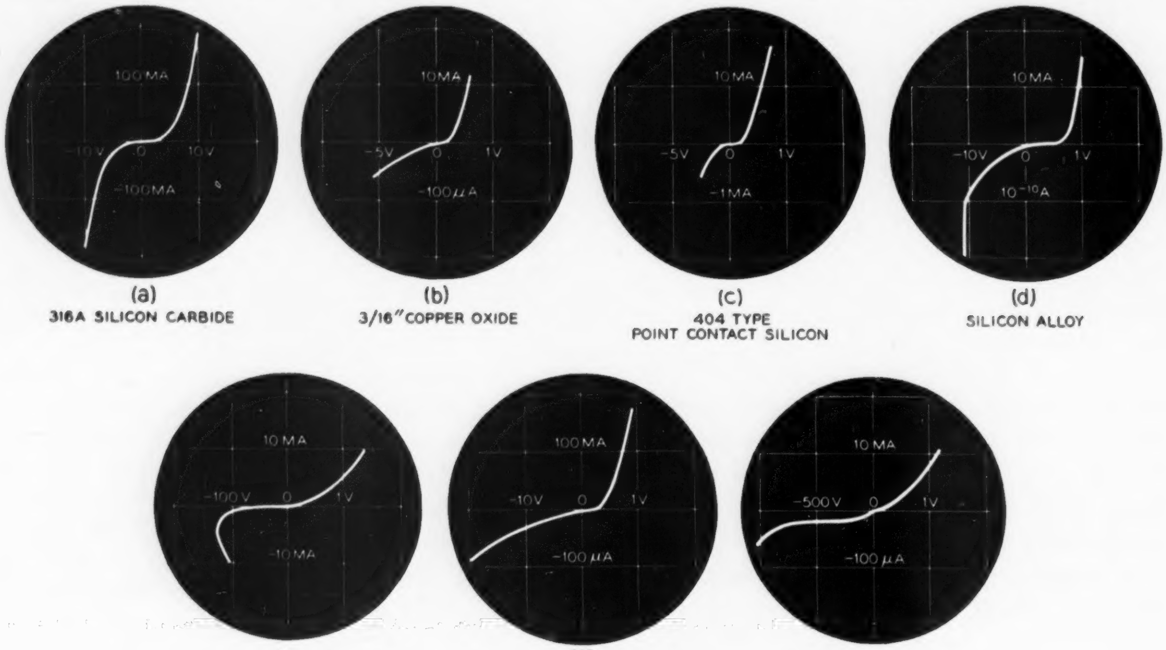
If an attempt is made to list all the uses of varistors, or the number of them in use or on order for new apparatus, even a person closely allied with the varistor field is likely to be impressed. In 1953, for example, Western Electric made over two million varistors for telephone use alone. A partial list of telephone uses would include varistors as rectifiers, modulators, vario-lossers, relay timing devices, mixers, converters and limiters – and, in the 500-type handset, as click reducers and line length equalizers. New designs now in the late stages of development seem to have potential use for telephone and military purposes far in excess of all current types.

Obviously, with a product in such wide use, and with the fields of application growing rapidly, varistor measuring techniques are important. Measurements must be made to assure continued high quality and to aid varistor development. If an undesirable trait is found, it must be quantitatively revealed by test so that experimental results may be analyzed and the product improved.

Physically, varistors take many different forms – from a tiny bead with two fine wires protruding to a large assembly of discs that can handle considerable power. They may be made of copper oxide, selenium, silicon, silicon carbide, germanium or certain alloys.

Above — Although not described in the text, this motor-driven forming machine, developed by the author, is a valuable tool in the varistor laboratory. It is used in making experimental 400-type varistors to provide close control of forming conditions and contact-spring deflection. Mrs. D. R. Ketchow is the operator.

Electrically, however, all varistors have one thing in common. When the voltage applied to the two terminals of a varistor is varied, the resulting current does not, in general, vary proportionally with the applied voltage. In Figure 1 some of the E-I (voltage-current) characteristics obtainable from varistors are shown plotted on linear scales. These curves are representative of certain types of silicon carbide, copper oxide, point-contact silicon and silicon alloy, and three types of germanium – point-contact, bead and p-n junction.



(a) 316A SILICON CARBIDE

(b) 3/16″ COPPER OXIDE

(c) 404 TYPE POINT CONTACT SILICON

(d) SILICON ALLOY

(e) 400 TYPE POINT CONTACT GERMANIUM

(f) BEAD TYPE GERMANIUM

(g) p-n JUNCTION GERMANIUM

Fig. 1 — Characteristic curves for different types of varistors. Note wide difference in scale values.

Except for silicon carbide, which has similar characteristics for either polarity of applied voltage, the varistors exhibit very different forward and reverse E-I curves. The point contact germanium varistor has a distinctive reverse curve in that it reaches a peak voltage and then doubles back under itself in a negative resistance region. The extremely small reverse current of the silicon-alloy junction varistor increases slowly over a range of voltages, and then breaks sharply into an almost vertical line at a critical voltage, sometimes referred to as the saturation voltage. Other differences of considerable magnitude are to be found between the characteristics of the different varistors if the scales associated with each set of curves are considered.

It is this diversity of E-I characteristics that gives varistors their wide field of usefulness. This same diversity, however, plus changes in characteristics from variations in frequency, temperature, and the particular circuit usage, results in a considerable list of special measuring problems. The modern varistor laboratory must be prepared to make measurements from dc to microwave frequencies and to control environment during tests – temperature, humidity, shielding from light and from unwanted fields. The usual dc and ac meters must be on hand, plus an array of oscillators, bridges, detectors, and broad-band oscilloscopes. In addition, it has been found necessary to develop certain special pieces of testing equipment peculiar only to varistor measurements.

Some people attempt to measure varistors with an ohmmeter; this is unfortunate, because of the misleading results they usually obtain. True, an ohmmeter can indicate whether a varistor is shorted or open, and whether the ratio of its front to back resistance differs from unity. The ohmmeter does not, however, test each varistor at a fixed and known value of current or voltage. Unless one of these parameters is fixed during test at a value closely related to the operating point in the circuit application, the test is likely to be of little value.

Formerly, when precise dc measurements were

needed in some application, process study, or life test, a simple set-up of battery, potentiometer, voltmeter, and milliammeter was used. This had several obvious disadvantages. Among these were falling battery voltage and the need to reset the potentiometer for each varistor because of imperfect voltage regulation. Even the small voltage drop across the milliammeter had to be computed and taken into account at each setting of the potentiometer, to offset a comparatively large error in the current readings when measuring non-linear varistors. There was also an ever-present hazard to the milliammeter from accidental short circuits or from varistors inserted with reversed polarity.

All of the above objectionable features have been overcome in several constant-voltage test sets using a series tube-type voltage regulator circuit with ample negative feedback. This circuit is shown in simplified form in Figure 2. The voltage across the varistor load is fed back to a dc amplifier (three stages in actual practice) and hence is stabilized, regardless of the IR drop across the ammeter or R1. Voltage across the load is set to the desired value by adjusting P1. Battery B1 acts as the reference voltage. The voltage output may be read by depressing the test push button; this short-circuits R1 and the ammeter, and connects the voltmeter to the load.

Resistor R1 is selected so that when about 150 per cent of full-scale current flows through the ammeter, sufficient IR drop is developed across R1 to fire thyratron V3. This latter operates the fast-acting mercury relay, which disconnects the load and short-circuits the ammeter. The effectiveness of this type of meter protection is perhaps best brought out in the 0 to 100-volt, 0 to 1-ampere constant-voltage test set. Here, with a meter in use that reads only four microamperes full scale, the load binding post may be short-circuited without fear of damaging the microammeter.

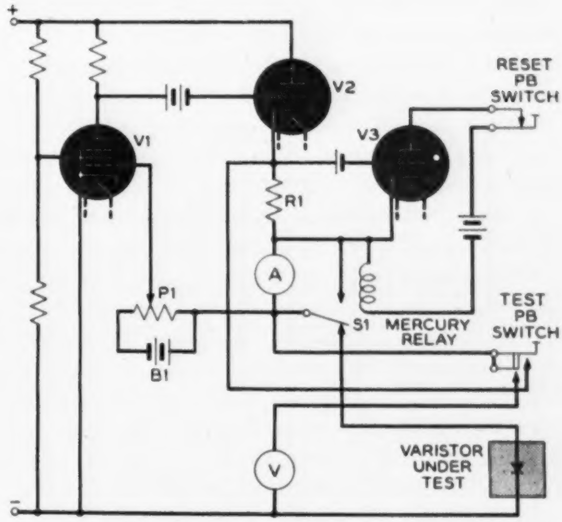


Fig. 2 — Simplified circuit of the constant-voltage varistor test set.

In this test set, matched input tubes and various compensating circuits are employed to obtain independence of line-voltage and load-current changes. The effect of line-voltage changes has been made negligible for our work, and the test set may be adjusted so that the steady state regulation versus load is better than $\pm$ 0.005 volts over the zero to one ampere range. This degree of regulation is maintained over a range of voltages from only a few tenths of a volt to one hundred volts. More recently a test set has been built for automatic varistor measurements at either constant E or constant I in which constancy of output is achieved entirely with large amounts of negative feedback. The newer test set uses, in addition to its high-gain dc amplifier, a special electro-mechanical circuit to obtain further stability. Batteries have been replaced by voltage-reference gas-tubes.

In some varistors, such as the copper-oxide type for example, the individual discs are completed before they can be electrically tested. The situation is somewhat different with point-contact germanium varistors. Here, after the point or "cat

Fig. 3 — Mrs. M. A. Erwin operating the micromanipulator. This device permits micrometer control of position and pressure of the various elements in experimental point-contact varistors.

whisker" is brought into contact with the germanium wafer, an electrical "forming" treatment must be applied, or a very poor rectifier results. An electric current is passed through the varistor during forming; this heats the germanium immediately beneath the point and thus converts a small hemisphere of it from n-type to p-type. This gives rise to a p-n junction – a barrier across which rectification occurs.

A standardized process is used on germanium varistors in the factory, but in the laboratory much can be learned by varying the materials, etching, contact pressure, and forming treatment. This work is greatly facilitated by the use of a micromanipulator in which a slice of germanium may be moved laterally and a contact-point vertically – all under the watchful eye of a microscope, with micrometer-type positioning controls. Such a manipulator is shown in use in Figure 3.

During such experimenting, a quick check is needed on the low-frequency E-I characteristics of the varistor under investigation. For this purpose nothing surpasses the convenience of an E-I curve tracer using a cathode-ray oscilloscope. With this device, the effects of experimental variations may be seen at a glance, and the resulting characteristics may be photographed if a permanent record is wanted. Such a curve tracer is shown in Figure 4. It provides maximum readability by simultaneously portraying forward and reverse E-I characteristics on independently adjustable voltage and current scales.

Voltage is displayed horizontally with forward voltage to the right of zero on a 1-volt per inch scale. Reverse voltages to the left of zero may be displayed on scales ranging from 1 to 500 volts per inch. Forward currents are shown vertically upward on scales of 1 microampere to 1 ampere per inch; downward, the scales for reverse currents range from 0.1 microampere to 100 milliamperes. Two mercury relays, vibrating at sixty cycles per second (cps) and properly phased, switch the diode input back and forth between the forward and reverse voltage supplies and cut resistors in and out at the proper time to give the desired voltage and current scales on the oscilloscope.

Fig. 4 — The 60-cycle curve-tracer and associated oscilloscope used with the micromanipulator to give continuous displays of varistor characteristics.

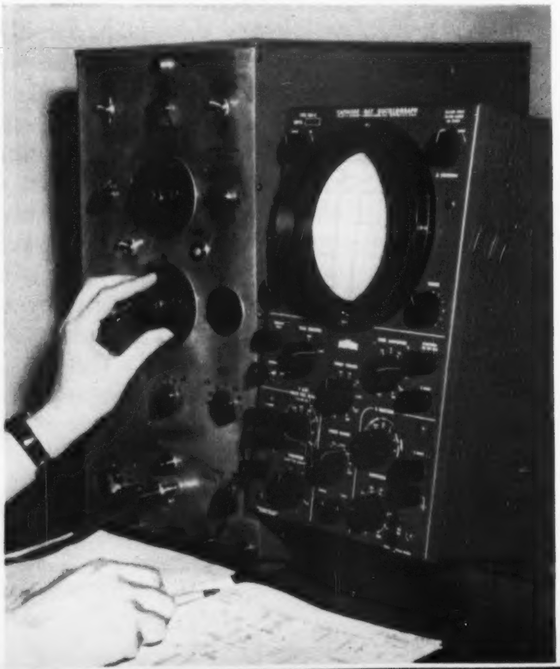


Fig. 5 — The special high-sensitivity curve-tracer is used with the silicon-alloy junction type varistors. Mrs. L. A. Leahy is plugging a varistor into the curve-tracer. The tiny diode is mounted in a plug-in jig for ease of handling. A vacuum oven is between two of the curve-tracers.

Figure 1(e) shows a typical forward characteristic in the first quadrant for a point-contact germanium diode and a typical reverse characteristic in the third quadrant, as seen on this curve tracer. Scales of 1 volt per inch and 100 volts per inch were used for the forward and reverse characteristics respectively. Current scales of 10 milliamperes per inch were used for both characteristics. Series resistance in the curve tracer protects the varistor from damage when it passes over its inverse peak into its negative resistance region, seen in Figure 1(e). Built-in electrical forming facilities greatly increase the usefulness of the device in experimental work. By using an external relay vibrating at about 15 cps the curve tracer may be made to look alternately at two varistors and to give an apparently simultaneous presentation of both sets of characteristics. This is a valuable tool in picking matched pairs for low-frequency use.

The recent advent of the silicon-alloy junction diode posed a very interesting problem in measuring technique, for here is a diode that is a better insulator in its reverse direction than are many electrical switches. This varistor appears to have a tremendous future in telephone switching, computers, modulators, and in a number of other fields. Such a diode may have a reverse current of only 5 micro-micro-amperes (5×10^{-12} amperes) at 10 volts – a reverse resistance of two million megohms! Yet, at one volt or more in the forward direction, its conduction may equal or exceed that of the familiar 400-type germanium varistor.

Small though the reverse currents are, they must still be measured, watched for stability, and kept under control. Available commercially-made current measuring meters were found to have inadequate sensitivity. Wall-type suspension galvanometers were too slow. The speed and convenience of the E-I curve tracer was well known to both shop and laboratory personnel, and so it was decided to investigate the feasibility of making a sensitive curve tracer for measuring the new varistor.

Figure 5 shows the instrument which resulted, in use in the varistor models laboratory. The diode to be tested is placed inside the aluminum can on top of the black box. This is done because light would reduce the back-resistance of the diode, and because ever-present sixty-cycle fields would otherwise result in pickup and in unwanted vertical deflections on the oscilloscope.

The required sensitivity was obtained by modifying a 3-inch oscilloscope to increase its vertical sensitivity, minimize hum pickup and to increase its input resistance in the vertical channel from 0.5 to 10,000 megohms. This latter was accomplished by working directly into the grid of a selected low grid-current Western Electric double triode – the 420A. On the most sensitive measuring scale (5×10^{-12} amperes per ½ inch division on the oscilloscope) the grid is allowed to "float." Its potential does not drift, however, because by properly adjusting heater temperature and voltages applied to the tube, the number of electrons reaching the grid is exactly balanced by those leaving it.

As can be seen from Figure 5, various independently adjustable scales are available for reverse voltage and for forward and reverse currents. The characteristics are traced out by rotating one or the other of two potentiometers that are located on the front of the curve tracer.

In such applications as vario-lossers, keyers, and the like, the ac resistance of varistors is quite important. Their ac resistance may be measured with bridges and by such techniques as substitution and slope-determining methods. However, where extreme accuracy is not required, the most convenient way for quick production checks is shown in simplified form in Figure 6. This is a somewhat novel use of the familiar series tube voltage regulator. The circuit tends to maintain a constant voltage across resistor R2, and since this is a constant resistance a constant current results in the varistor connected above it. If a small ac signal voltage is impressed across the cathode resistor of V1, a practically equal ac voltage is developed across R2. This causes a small constant alternating component to be superimposed on the current flowing through the varistor. Hence, a high-impedance ac voltmeter connected across the varistor will read values directly proportional to the ac resistance of the varistor, and may be calibrated to read directly in ohms. The circuit may also be modified to apply a constant-voltage bias rather than a constant-current bias to the varistor that is being tested.

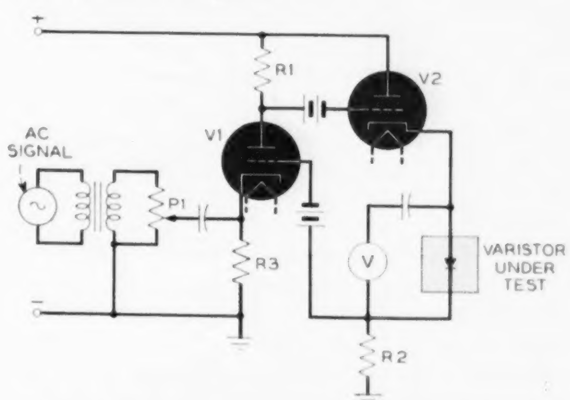


Fig. 6 — Simplified circuit of a varistor measuring device that gives a direct reading of ac resistance.

The reverse-recovery effect, referred to as "hole storage," "enhancement," and other names, is one of the properties of varistors that is most difficult to measure. This effect comes to light when the varistor is very suddenly switched from its conducting to its blocking condition, the difficulty being that the expected high back-resistance does not immediately appear. If, after conducting forward current, the varistor is switched to a constant reverse current, the reverse voltage builds up across it more slowly than ordinary capacity measurements indicate that it should. This reverse-recovery time is measured in tenths of microseconds in the case of the point-contact germanium varistor.

If the same varistor is switched from a forward voltage to a reverse voltage, a high, exceedingly steep and narrow spike of reverse current appears, followed by a "tail" having a time-constant of the order of 0.05 microsecond. This is shown in Figure 7. Such behavior, needless to say, is highly undesirable in high-speed switching and computer applications. On the other hand, it has recently been put to very good use in converters in UHF television receivers. It has been found that such varistors can be made to produce many harmonics and so make excellent frequency multipliers for generating frequencies in the vicinity of 1,000 mc.

A pair of special square-wave generators were built in the laboratory to study the reverse recovery effect. Their output pulses have rise and fall times of about 0.02 microsecond, and can be controlled in pulse-width, amplitude and time. This varistor measuring equipment has proved very useful in studying the slower p-n diode. For studying point contact varistors, the sudden, chatterless closure of a mercury relay has provided the most satisfactory square wave. It would be highly desirable though, if the relay could operate say up to at least 1,000 cps instead of only around 100 cps, and also if it could be made to give off a slightly advanced synchronizing pulse. However, what would really facilitate reverse-recovery studies would be an oscilloscope with very fast sweeps, great brilliancy, good sensitivity and above all, a bandwidth of about 1,000 megacycles. Our present oscilloscope with its 70 megacycle bandwidth can barely suggest the existence of the reverse current spikes. These spikes have been seen, however, on a special oscilloscope using no amplifier and with a response up to about 200 megacycles. Unfortunately, because of the raster-type of presentation and relatively low sensitivity, it was difficult to obtain accurate measurements of the sharp, narrow spikes. Better measuring instruments for this type of test will undoubtedly lead to better varistors, just as have the other and more successful testing techniques and equipments described earlier in this article.

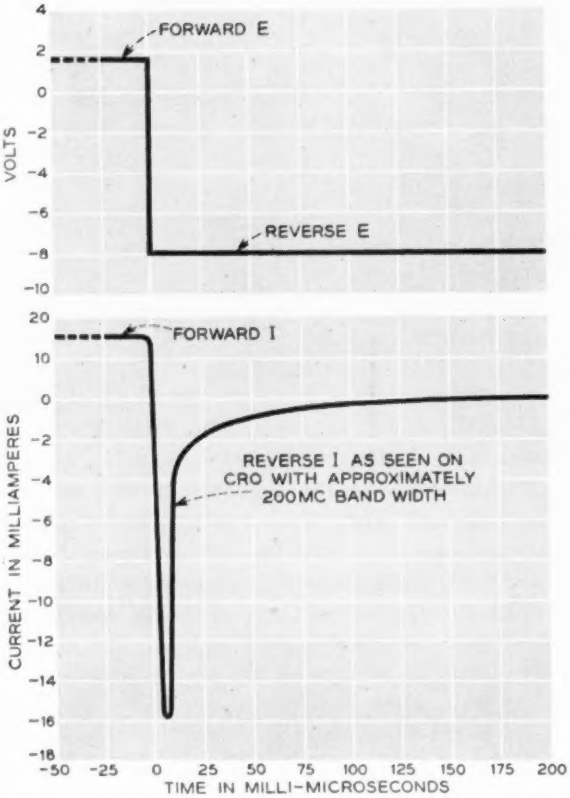


Fig. 7 — The reverse-recovery effect that occurs when the polarity is rapidly reversed.

THE AUTHOR

ROYER R. BLAIR, who came to the Laboratories in 1930, was for some time engaged in the development of apparatus associated with the coaxial system. During World War II he was concerned with military projects, spending a year at Hawthorne on testing and production problems. After the war he turned his attention to the design and testing of germanium, silicon and copper oxide varistors for use in coaxial cable and microwave carrier systems. He is currently conducting fundamental studies of transistor circuits for use in switching and computing. Mr. Blair received the B.S. degree in E.E. from Rose Polytechnic Institute in 1930 and the M.A. degree in physics from Columbia University in 1939. He has been a long time member of the New York Electrical Society and Tau Beta Pi.

Dr. Kelly Receives Honorary LL.D.

Gaylord P. Harnwell, president of the University of Pennsylvania, awarding honorary LL.D. degree to Dr. Kelly.

M. J. Kelly was awarded the honorary degree of Doctor of Laws at the annual graduation ceremonies of the University of Pennsylvania in Philadelphia on June 16. In conferring the degree, the University cited Dr. Kelly as follows:

"By your leadership of the more than 3,000 scientists and engineers in one of the world's greatest research laboratories you have materially influenced the economic and social patterns of our society.

"By your earlier work in that laboratory you have shown yourself an investigator and creator of high order in the realm of physical science and engineering development.

"By your public-spirited contribution of time and effort at the call of your country you have helped shape national policy to the benefit of all.

"You are a true representative of the great mixed field of science and technology which so enriches our lives today."

Dr. Kelly holds two other honorary degrees, awarded in recognition of his contributions to science and technology. In 1936 his alma mater, the Missouri School of Mines and Metallurgy, conferred on him the honorary Doctor of Engineering degree, and in 1946 the University of Kentucky awarded him an honorary Doctor of Science degree.

New Super-Speed Teletypewriter Placed in Service

A new super-speed teletypewriter system was recently put into operation on an experimental basis between the New York headquarters of the Associated Press and the offices of the Boston *Herald* and the Boston *Traveler*. The new system transmits at a rate of 600 words per minute, several times as fast as present equipment. In this trial installation complete stock market reports from the New York Stock Exchange are sent to the Boston newspapers in only a few minutes.

Designed by the Teletype Corporation in conjunction with the Laboratories and Long Lines, the system consists of mechanical tape reading and electronic transmitting equipment at the sending end, and at the receiving end, electronic equipment actuating a mechanical reperforator. The perforated tape is fed into Teletypesetter machines to produce justified lines of type ready for the presses. The new system is so fast that a number of Teletypesetters operating at standard speed are required to keep up with the tape as it is punched.

Transmission is over a special wideband voice-frequency telegraph circuit operating on a carrier telephone channel.

H. F. Dodge Delivers Edgar Marburg Lecture at A.S.T.M. Meeting

H. F. Dodge, Quality Results Engineer at the Laboratories, recently presented the 1954 Edgar Marburg Lecture before the annual meeting of the American Society for Testing Materials in Chicago. His subject was *The Interpretation of Engineering Data*. The Marburg lecture is given each year by a leader in his field to emphasize the importance of furthering the knowledge of materials. Mr. Dodge received the A.S.T.M. Award of Merit in 1950, and in 1949 was Shewhart Medalist of the American Society for Quality Control.

Time-of-day announcements have been a feature of telephone service for many years. An automatic time-announcing machine has been adopted for such service in more than 100 cities, but the accuracy of its time announcements depends on the frequency of its power supply. The Laboratories has developed a power supply for this use where commercial power supplies are inadequate for the service. It contains duplicate channels to provide continuous operation in the event that one channel fails, and means for re-setting or correcting inaccuracies in time announcements without interrupting service.

Regulated-Frequency Power Supply for Time-of-Day Machine

H. M. OWENDOFF *Audio Facilities*

One of the primary factors in modern civilization is time. The average person spends most of his life following set patterns, each based on specific times. Awakening, eating, traveling to and from work, attending movies, ball games, and other activities, all depend on knowing the time. Regular "time-of-day" telephone announcements were inaugurated in New York City in 1928, and this service has grown until approximately 70,000 calls per day were handled during World War II. As the need for this type of service increased, time-of-day announcements were added in other cities and are accepted and even expected by the public.

The problems encountered in providing such time service are many, particularly in the smaller cities. Manually operated time bureaus, such as the early 1B announcement system in New York City, make such exacting demands on operators that their rotation at frequent intervals is required. More technical in nature is the need for an accurate time standard for timing the announcements.

With the extension of time service to an increasing number of cities, the need for automatic facilities to replace manual time bureaus became apparent. This has resulted in the development of the 2B and 4A time announcement systems,* in which all time announcements, except those under emergency conditions, are made by automatic time-announcing machines. Such machines ordinarily operate from commercial 60-cycle power lines and the accuracy of their time announcements depends on the frequency regulation of the power system. Where accuracy requirements for such time service in a particular area cannot be adequately met by operating time-announcing machines on commercial power, suitable 60-cycle sources of power must be provided.

A regulated-frequency power supply was de-

Above—The author adjusts the time-signal receiver at the Portland installation.

* Record, *September*, 1953, *page* 356.

signed by the Laboratories, utilizing tuning-fork oscillator equipment developed by American Time Products, Incorporated, of New York City, for use in their precision watch-timing equipment. The regulated frequency supply operates the time-of-day machine used in automatic time-announcing applications. Two separate and independent 60-cycle power sources are provided in the regulated supply, each source incorporating a highly stable tuning fork oscillator and a power amplifier. Control equipment, common to both channels, incorporates monitoring and switching facilities.

Two types of regulated-frequency power supply have been developed. In the standard equipment, Figures 1 and 2, the frequencies of the two channels may be individually varied within narrow limits ($\pm$ 100 parts per million) and can be set to the correct frequency by comparing the time indications of monitoring clocks with government time signals. Special equipment was designed for the New York City installation where the frequencies of the two channels are closely controlled by the Bell System Precision Frequency Standard at Murray Hill, which is available through the Long Lines Department of the A.T.&T. Company in New York.

The oscillators in the regulated-frequency power supply use 240-cycle tuning-forks in temperature-controlled ovens as stable frequency sources. Pairs of cascaded 2:1 frequency dividers then reduce the frequency from each tuning-fork oscillator to 60 cycles per second. Two stable outputs are provided per frequency divider: one 60-cycle output to operate a monitoring clock and another output to a power amplifier.

The power amplifier output circuit contains a continuously-variable motor-driven 60-cycle phase shifter that permits the frequency to be changed to either 61 or 59 cycles without affecting the frequency of the clock output channel. Operation of this phase-shifter, or "time corrector," causes the announcing machine to gain or lose about one second per minute, and permits time corrections to be introduced while the machine is in use without noticeable effect on the quality of the recorded announcements.

Power amplifiers in each channel can furnish 50 watts continuously at 60 cycles, and up to 75 watts for short periods. Each amplifier is equipped with an under-voltage alarm circuit. When the amplifier output voltage falls below 90 volts, an alarm

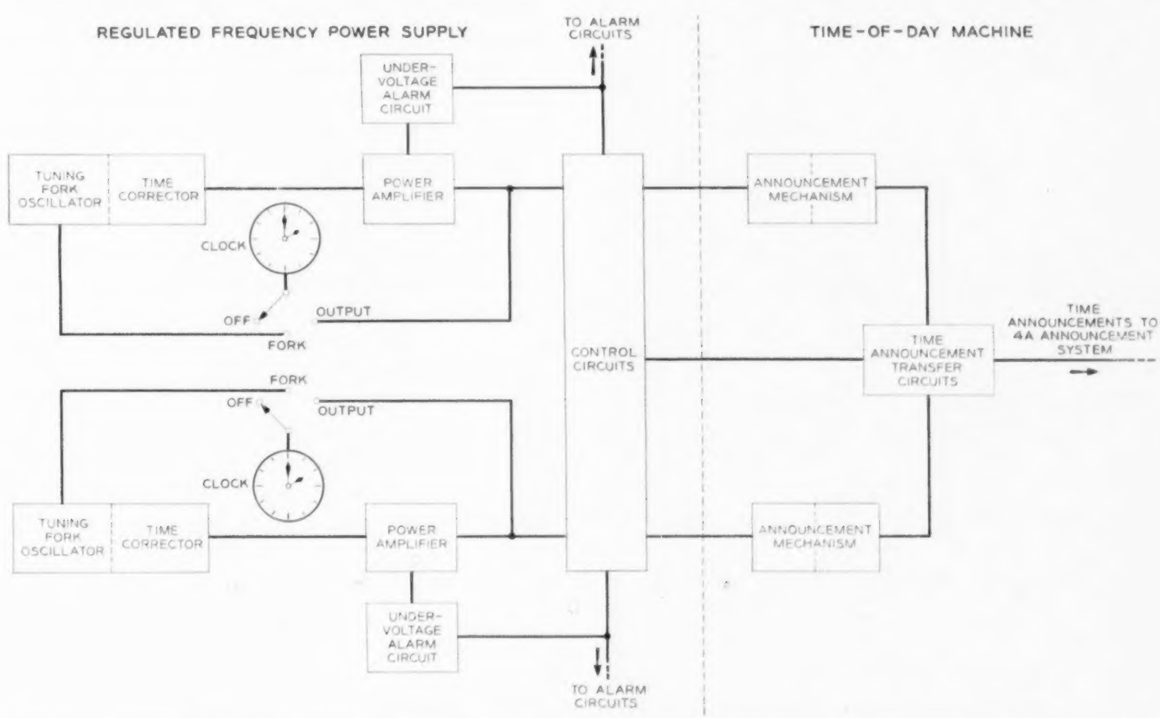


Fig. 1 — A block diagram of the regulated-frequency power supply for announcement machine.

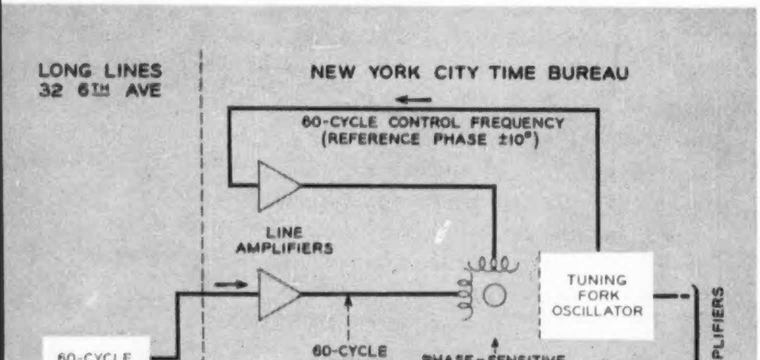
sounds and the drive motor of the associated announcing-machine channel is automatically transferred to 60-cycle commercial power.

Control equipment for the regulated-frequency power supply is mounted on two control panels. The main control panel, Figure 2, contains clocks for monitoring each channel, facilities for controlling the operation of each mechanism of the time announcing machine, and means for comparing the settings of the monitoring clocks and time announcements from the machine with standard time signals. The power control panel contains circuit breakers for the 48-volt office battery supply and the commercial 60-cycle power supply circuits. This panel also contains power-factor correcting capacitors, and power relays for connecting the machine's motors to the regulated supply.

Each monitoring clock in the main control panel may be connected either to the direct output of its associated tuning-fork oscillator or to its power amplifier. When connected to the power amplifier, a clock may be caused to gain or lose time at the rate of one second per minute by using the time corrector. When connected to the tuning fork oscillator, operation of the time corrector has no effect on the clock.

Fig. 2 — A regularly scheduled time check is made by Rodney Lundstrom at Portland.

Fig. 3 — The arrangement in New York City uses the Bell System Precision Frequency Standard to continuously monitor and control the frequency of the tuning-fork oscillators.



Since the output of each power amplifier is limited, the motors of the time-of-day machine must be started on commercial power. Synchronizing lamps indicate when the phase of each regulated channel is the same as that of the commercial power supply, and controls on this panel permit the announcing machine motor to be transferred to the regulated supply when it is in phase. Other controls determine which announcing channel is connected to the 4A announcement system, and automatically transfer the announcement system to the other channel if the channel in use fails or is disconnected from its regulated-frequency supply.

Time signals for checking the accuracy of the monitoring clocks and time announcements are received on a pre-tuned time-signal radio receiver. The clocks are checked visually by comparison with the time signals; the accuracy of time announcements from the announcing machine is checked audibly by combining time signals and announcements in a monitoring headset, Figure 2.

The time-announcing machine, when operated from the regulated-frequency power supply, will furnish time announcements accurate to better than one second a day. For most applications, time announcements having this degree of accuracy are

entirely acceptable. However, in New York City, the endeavor is to hold time announcements to an accuracy of better than 1/20 second. Continuous automatic correction of the frequencies of the two oscillators provides this accuracy. Automatic frequency correction is accomplished by a motor-driven frequency control that compares the oscillator frequency with the standard, and applies a frequency correction whenever the phase difference between the two frequencies is on the order of 10 degrees. The connecting circuits and modifications of the oscillators to provide automatic frequency control are shown in Figure 3.

In other respects, the New York City regulated frequency power supply is the same as the previously developed regulated supply. The same power amplifiers and the same main and power control panels are employed. However, the time-signal receiver and the circuits for checking the time announcements are used only during initial adjustment. For precise time checks, a stroboscopic "time comparator," originally installed in the 1B announcement system in New York City, has been retained and modified to provide a very precise indication of the accuracy of time announcements from the announcing machine. The start of time tones from the announcing machine may be compared with standard time signals to within 1 millisecond; frequent time checks insure that under normal operating conditions, time announcements will be within 10 milliseconds of official time.

Since the New York City equipment differs from the standard equipment only in automatic setting of the oscillator frequency, failure of either incoming 60-cycle standard-frequency control circuit does not interrupt the operation of the regulated-frequency supply. Instead each oscillator "remembers" where its frequency control was last set and continues to operate at that frequency without benefit of automatic correction of any slight oscillator drift until the standard-frequency circuits are restored.

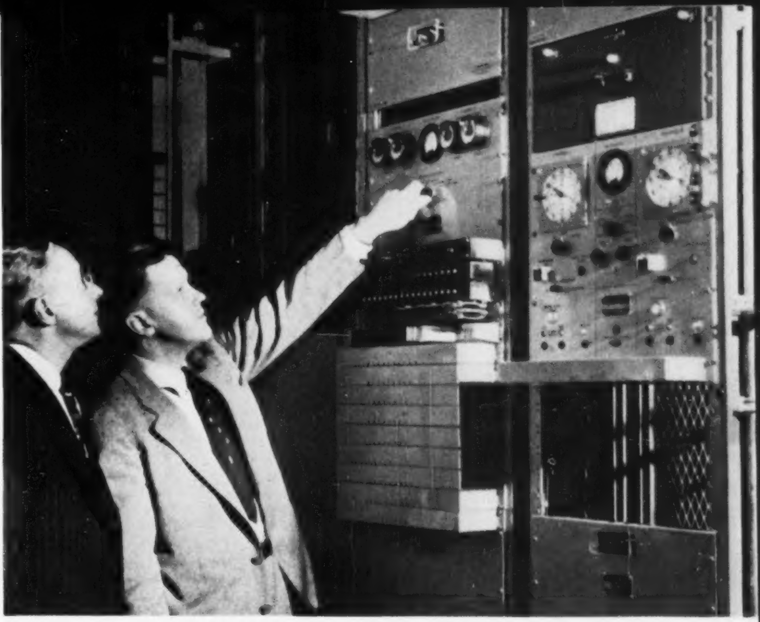


Fig. 4 — Vincent Amoroso of the New York Telephone Company and A. E. Gerbore of the Laboratories inspect the time-of-day equipment in New York City.

Regulated-frequency power supplies have been installed in Portland, Ore., Baltimore, Detroit, and Boston. The Portland and Baltimore installations have operated continuously for almost three years. In both these systems, daily time variations have not exceeded one second per day except under trouble conditions, and in the Baltimore installation the variation has not exceeded one-quarter second over several two-week periods.

The New York City equipment has operated continuously for nearly two years. Controlling this equipment from standard-frequency sources has proved to be a wise measure because it has been possible to maintain 50-millisecond accuracy of time announcements even where the standard-frequency supply has been interrupted for some time.

THE AUTHOR

Harold W. Owendoff entered the Laboratories in 1929 as a student assistant. In 1933 he left the Laboratories to attend the State University of Iowa, receiving his B.S. degree in Electrical Engineering in 1935. Early in 1936 he rejoined the Laboratories and was concerned with the development of amplifiers for broadcasting systems. Since then he has worked on the development of devices for testing hearing, vibration measuring equipment for the government, airborne radar equipment, and sound level meters and level recorders. He also worked on two military projects and is presently concerned with telephone answering devices. Mr. Owendoff received his M.S. degree at Stevens Institute of Technology in 1948. He is an associate member of Sigma Xi.

Patents Issued to Members of Bell Telephone Laboratories During the Month of May

Bangert, J. T. – *Wave Transmission Network Utilizing Impedance Inversion* – 2,679,633.

Bellows, B. C., Jr. – *Directional Coupler* – 2,679,632.

Chick, A. J., and Speck, L. J. – *Grid for Electron Discharge Devices* – 2,678,486.

Cisne, L. E. – *Formation of Electrode Tips by Electric Current Heating* – 2,679,570.

Darlington, S. – *Pulse Transmission* – 2,678,997.

Drazy, E. J. – *Frequency Discriminator* – 2,679,585.

Edwards, C. F. – *Balanced Wave Guide Branching System* – 2,679,582.

Entz, F. S., Pullis, G. A., Ressler, R. E., Soffel, R. O., and Weber, L. A. – *Signaling System for Carrier Telephone Transmission* – 2,677,726.

Felch, E. P., Jr., and Slonczewski, T. – *Voltage Indicating and Recording Device* – 2,679,630.

Frantz, G. R. – *Linearity Measuring Scheme* – 2,678,383.

Gooderham, J. W. – *Digit Reconstruction System* – 2,678,-968.

Holden, W. H. T. – *Signaling System* – 2,678,409.

Lozier, J. C., and Weller, D. C. – *Temperature-Controlled Induction Furnace* – 2,678,959.

McKay, K. G. – *Photomultiplier Utilizing Bombardment Induced Conductivity* – 2,678,400.

Newby, N. D. – *Capacitative Commutator* – 2,679,551.

Olsen, K. M. – *Production of Single Crystals of Germanium* – 2,679,080.

Pullis, G. A., see Entz, F. S.

Ressler, R. E., see Entz, F. S.

Slonczewski, T., see Felch, E. P., Jr.

Soffel, R. O., see Entz, F. S.

Speck, L. J., see Chick, A. J.

Smith, K. D. – *Linearity Measuring Scheme* – 2,678,427.

Vaughan, H. E. – *Signal Sender Comprising Motor Driven Capacitative Commutator* – 2,678,435.

Weber, L. A., see Entz, F. S.

Weller, D. C., see Lozier, J. C.

Young, W. R., Jr. – *Mobile Radio System* – 2,678,998.

Papers Published by Members of the Laboratories

Following is a list of the authors, titles, and place of publication of recent papers published by members of the Laboratories:

Blaha, A. L., see Davis, T. E.

Chase, F. H., Hamilton, B. H., and Smith, D. H., Transistors and Junction in Telephone Power Plants, B.S.T.J., **33**, pp. 827-859, July, 1954.

Clark, M. A., An Acoustic Lens as a Directional Microphone, I.R.E., Trans. AU-2, No. 1, pp. 5-7, Jan.-Feb., 1954.

Davis, T. E., and Blaha, A. L., Electronic Relay Tester, B.S.T.J., **33**, pp. 925-938.

Fletcher, R. C., Yager, W. A., Pearson, G. L., Holden, A. N., Read W. T., and Merritt, F. R., Spin Resonance of Donors in Silicon, Letter to the Editor, Physical Review, **94**, pp. 1392-1393, June 1, 1954.

Geballe, T. H., and Hull, G. W., Seebeck Effect in Germanium, Physical Review, **94**, pp. 1134-1140, June 1, 1954.

Green, E. I., The Decilog: A Unit for Logarithmic Measurements, Elec. Eng., **73**, pp. 597-599, July, 1954.

Gross, A. J., see Tanenbaum, M., Heffner, H., Analysis of the Backward Wave Traveling Wave Tube, I.R.E. proc., **42**, pp. 930-937, June, 1954.

Hamilton, B. H., see Chase, F. H.

Hohn, F. E., The Conference on Training in Applied Mathematics, American Mathematical Monthly, **61**, pp. 242-245, April, 1954.

Holden, A. N., see Fletcher, R. C.

Hull, G. W., see Geballe, T. H.

Jaffe, Hans, see Mason, W. P.

Ladd, F. E., 50-Mc TVI – Its Causes and Cures, Part I, QST, **38**, p. 21, June, 1954. Part II, p. 32, July, 1954.

Mason, W. P., and Jaffe, Hans, Methods for Measuring Piezoelectric, Elastic and Dielectric Coefficients of Crystals and Ceramics, I.R.E. Proc., **42**, pp. 921-930, June, 1954.

Merritt, F. R., see Fletcher, R. C.

Pearson, G. L., see Fletcher, R. C.

Pfann, W. G., see Tanenbaum, M.

Read, W. T., see Fletcher, R. C.

Shockley, W., Negative Resistance Arising from Transit Time in Semiconductor Diodes, B.S.T.J., **33**, pp. 799-826, July, 1954.

Smith, D. H., see Chase, F. H.

Suhl, H., and Walker, L. R., Topics in Guided Wave Propagation Through Gyromagnetic Media Part II – Transverse Magnetization and Non-Reciprocal Helix, B.S.T.J., **33**, pp. 939-986, July, 1954.

Sumner, E. E., Some Fundamental Problems in Percussive Welding, B.S.T.J., **33**, pp. 885-896, July, 1954.

Sunde, E. D., Theoretical Fundamentals of Pulse Transmission – II, B.S.T.J., **33**, pp. 987-1010, July, 1954.

Tanenbaum, M., Gross, A. J., and Pfann, W. G., Purification of Antimony and Tin by a New Method of Zone Refining, J. Metals, **6**, pp. 762-763, June, 1954.

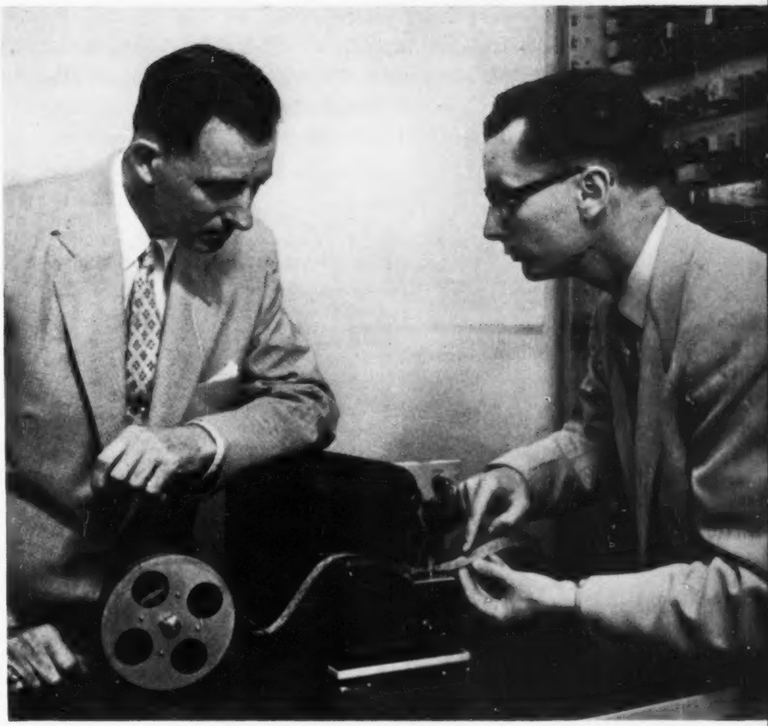
Turner, E. C., Telephone Growth Forecasting – Part I, Telephony, **146**, pp. 17-19, 48, June 12, 1954. Part II, Telephony, **146** pp. 23-25, June 19, 1954.

Walker, L. R., see Suhl, H.

Wick, R. J., Solution of the Field Problem of the Germanium Gyrator, J. Appl. Phys., **25**, pp. 741-750, June, 1954.

Yager, W. A., see Fletcher, R. C.

Automatic Progression Trunk-Test Circuit



H. D. CAHILL *Switching Systems Development*

In the design of automatic telephone switching systems like the No. 5 crossbar, provision must be made for testing the serviceability of trunks that carry customers' conversations. To make these testing operations automatic, a new circuit has been devised which uses a perforated tape to control a variety of test programs. This new method of control permits unlimited flexibility in the order of selecting trunks for testing. It also eliminates the necessity of making wiring changes in the test frame when trunks are added or rearranged.

Soon after the introduction of dial switching systems, automatic test circuits were designed to perform routine tests and to locate specific troubles. As automatic switching systems became more complex, new testing methods were needed to provide continuously reliable service and to keep maintenance costs down. These testing circuits are generally of two types: the "direct access" type where separate wiring is used to connect the test circuit to the equipment being tested, and the second type, where the test circuit uses existing office equipment to establish a connection. Arrangements for testing trunk circuits in the No. 5 crossbar automatic switching system are of this second type, and the controls for these test circuits are located on what is known as the master test frame. The original design of the No. 5 crossbar system provided for the testing of trunks from this frame, using a simple test circuit that was operated manually, with no provision for progressing automatically from trunk to trunk.

To test trunks progressively and on a fully automatic basis, a new test circuit called the automatic progression trunk-test circuit has been designed. It obtains access to trunks via the regular switch train and uses perforated Teletype tape and a standard Teletype reader, called a transmitter-distributor, to direct the switch train to the trunks and to tell the test frame what tests to make on each trunk. One of these transmitter-distributors is seen in the above photograph.

Figure 1 shows by block diagram the circuits

Above—The author (left) and V. J. Acquaviva discussing the tape that feeds into the automatic progression trunk-test equipment.

used in setting up a typical test connection. Dotted lines indicate circuits used for a brief time to establish the test connection. The transmitter-distributor is also shown to illustrate how tape information is transferred first to register relays in the test circuit, released. The sketch is expanded over that of Figure 1 to show how the test circuit gains access to the trunk relay equipment over leads T and R, or to the cable pair over leads T1 and R1. The trunk is held by relays in the originating test line, which in this

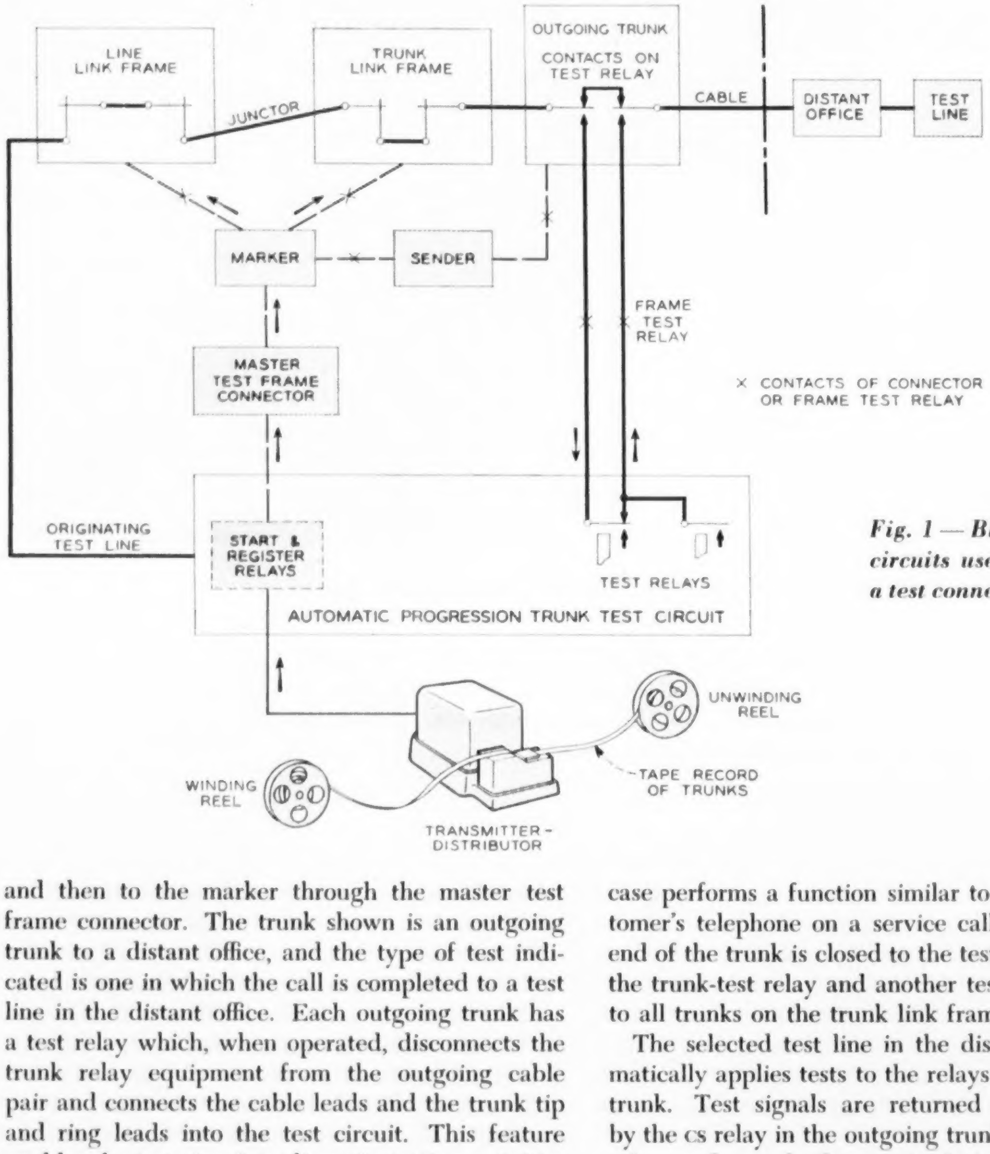


Fig. 1 — Block diagram of circuits used in setting up a test connection.

and then to the marker through the master test frame connector. The trunk shown is an outgoing trunk to a distant office, and the type of test indicated is one in which the call is completed to a test line in the distant office. Each outgoing trunk has a test relay which, when operated, disconnects the trunk relay equipment from the outgoing cable pair and connects the cable leads and the trunk tip and ring leads into the test circuit. This feature enables the test circuit to direct its testing activities toward the trunk relay equipment, or toward the distant office over the cable pair as required. In addition it may, as shown in Figure 1, re-establish the connection between the trunk talking leads and the cable leads to permit selections to be made in the distant office.

Figure 2 shows in simplified form the test connection after the common control elements have case performs a function similar to the calling customer's telephone on a service call. The outgoing end of the trunk is closed to the test circuit through the trunk-test relay and another test relay common to all trunks on the trunk link frame.

The selected test line in the distant office automatically applies tests to the relays of the incoming trunk. Test signals are returned and recognized by the CS relay in the outgoing trunk. A contact on relay CS forwards the received signals to the test circuit over lead CS. The signals are in reality a series of pulses that the test circuit counts and then advances automatically at the proper time as each applied test is successfully completed. If one of the tests fails, the series of pulses will be interrupted. The test circuit stops and displays lamp signals indicating the nature of the trouble.

When the trunk to be tested is an intraoffice trunk,

the test circuit and the common-control circuits function in the same general way to seize the trunk as already described for the interoffice trunk.

Intraoffice trunks are those used for completing calls between customers in the same office. Since

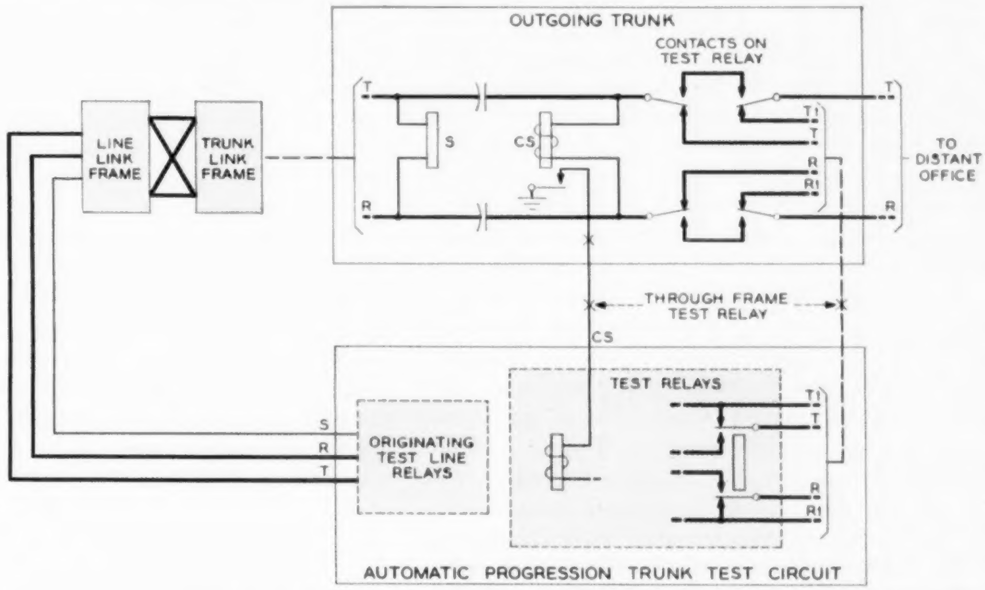
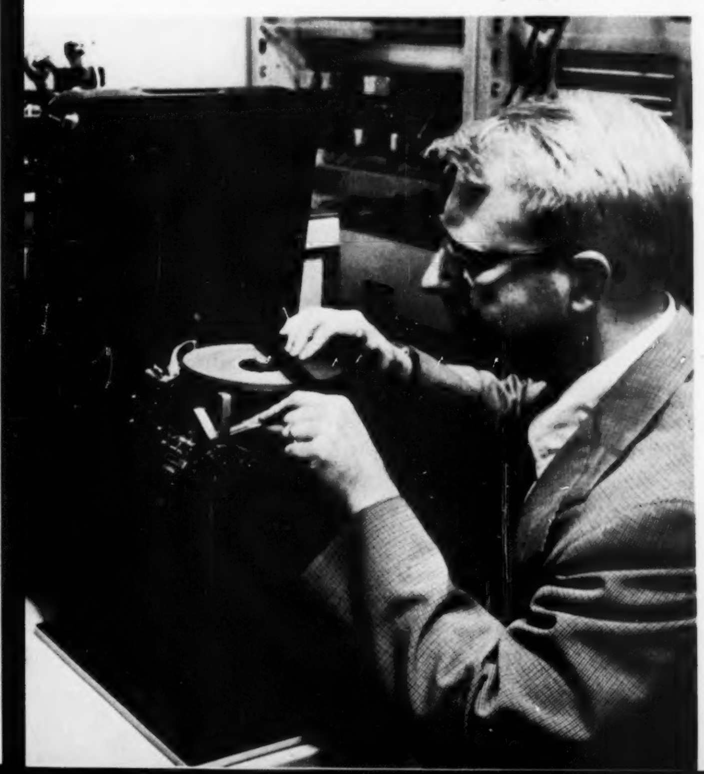


Fig. 2 — Simplified schematic showing test connection to an interoffice trunk after common control circuits have released.

these trunks do not connect to another office, they are not equipped with the test relay previously described to isolate the trunk from the cable pair while testing. Other methods must instead be used to gain access to the terminating end of the trunk.

Fig. 3 — M. R. McCann, Jr., starting unperforated tape through reperforator preparatory to making new tape record used to control automatic trunk-test program.



The test circuit solves the problem by directing the marker to complete the call back to the test circuit through a terminating test line assigned for this purpose on the line link frame. Figure 4 shows the test connection in simple form after the intraoffice trunk has been seized and the common-control circuits have released. Relays forming a part of the originating and terminating test lines in the test circuit serve to hold the trunk, and to enable the test circuit to apply tests as desired to either end of the trunk.

The preceding paragraphs tell how an individual trunk is seized, but a test circuit featuring automatic progression from trunk to trunk must itself be governed by a program that determines the order in which trunks are selected and tested. In most automatic test circuits, this program is controlled by a wiring pattern forming a part of the test circuit. The automatic progression trunk-test circuit, however, through the medium of its Teletype reader and perforated tape, introduces a new method for control of the test program.

Each of the several hundred trunks tested is represented by a combination of holes in the prepared tape. Figure 5 represents an enlarged section of tape perforated with information required for selecting one trunk. The two-out-of-five code used for each line is also shown. As indicated in the sketch, any two holes represent a number 0 to 9 in accordance with the two-out-of-five additive system. Thus, for instance, an 8 is represented by the two holes 7 and 1.

The tape is fed into the transmitter-distributor at the start of the testing program. The transmitter-distributor reads the code information from the tape and records the information on register relays in the test circuit. The information read is in a form that the test circuit can use to select and test the desired trunk.

Information appearing on the tape for each trunk is in thirteen adjacent lines, occupying about one inch of tape. Thirteen such lines along the tape make up a section that contains all information necessary for selecting one trunk, for controlling the test circuit operation to suit the type of trunk selected, and for determining the type of test that is to be made.

The complete section shown in Figure 5 contains a message to the test frame, which may be translated to read as follows: "On trunk frame 09, select the trunk marked as trunk 15, in the group outgoing to office Oregon-3. Make a test on this trunk to be sure that machine ringing will not be cut off from the line before the call has been answered, and that it is cut off when the call is answered; check that the supervisory relays in the outgoing trunk function properly; also test the supervisory relays in the incoming trunk in office Oregon-3."

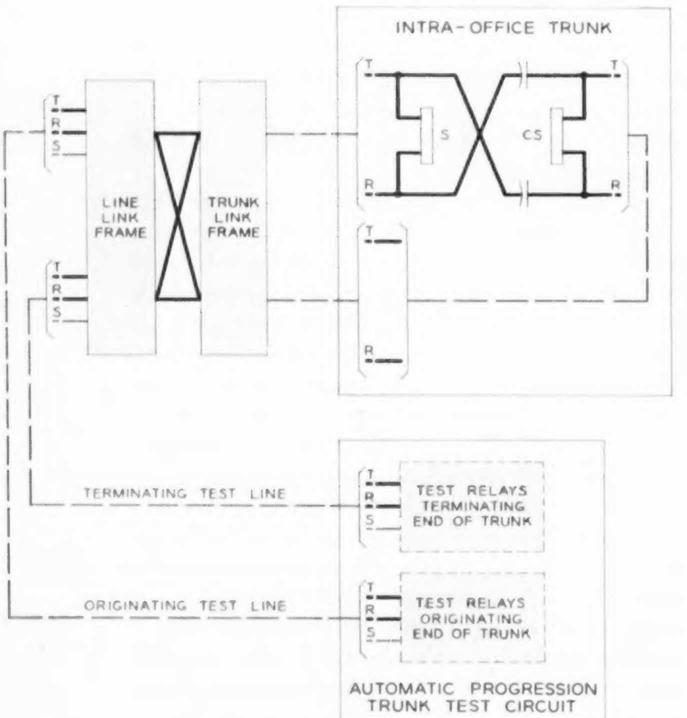


Fig. 4 — Simplified schematic showing condition of test connection after intraoffice trunk has been seized and after the common-control circuits have released.

If this message seems like a large order for a few holes perforated in code form, a closer examination of the coded information in Figure 5 will reveal how easily these orders are interpreted.

The first three lines represent the three digits of the office code (673), and they are the same digits that are recorded in the switching equipment when a customer calls a number in office Oregon-3. Line 4 is zero, indicating that the call terminates within the local numbering area. The class of service tens and units digits (needed by the marker) are recorded on lines 5 and 6. Digit three, perforated in line 7, tells the test circuit that the trunk is arranged for AMA operation.

Line 8 tells the test circuit what kind of test to make. In this case the perforated zero demands a test of the ringing and supervisory features mentioned in the above translated instructions. Next in the translation, lines 9 and 10 tell the marker that the wanted trunk is on frame number 09, and lines 11 and 12 designate the trunk as a number 15 within a block of 20. The last line is perforated as zero to tell the marker that it is not necessary to "route advance" to find the wanted trunk.

When all lines have been read and when the information has been stored in the register relays, the marker is automatically seized through the master test frame connector as already described. When the trunk has been tested for the features designated by the tape information, the test circuit releases and at once asks the transmitter-distributor to advance and read the next section of information on the tape. The new section will usually call for the same kind of test on another trunk, but if desired, the same trunk may be reseized and tested in a different class. This versatility is useful when testing trunks arranged for combinations of two or more of the four possible classes – flat rate, message rate, AMA or coin. The test may be made for any class, or passed for any class at will.

Tapes used in the testing program are perforated by another Teletype machine called a reperforator, shown in Figure 3. This machine, which is equipped with a roll of unperforated tape, is controlled by keys on the test frame. An initial test tape is made by first operating a "class" key to prepare the machine and the test frame for the perforating function, and then depressing other keys one at a time, each key corresponding to the numeral that represents one line on the tape. Two or three blank lines, controlled by a "space" key, are left on the tape between each successive section of the trunk

information. These unperforated areas mark the individual trunk section. Blank areas large enough to record handwritten information may be applied (if desired) to mark the beginning of information applying to groups of trunks. Before a tape becomes unreliable from long usage, a duplicate tape

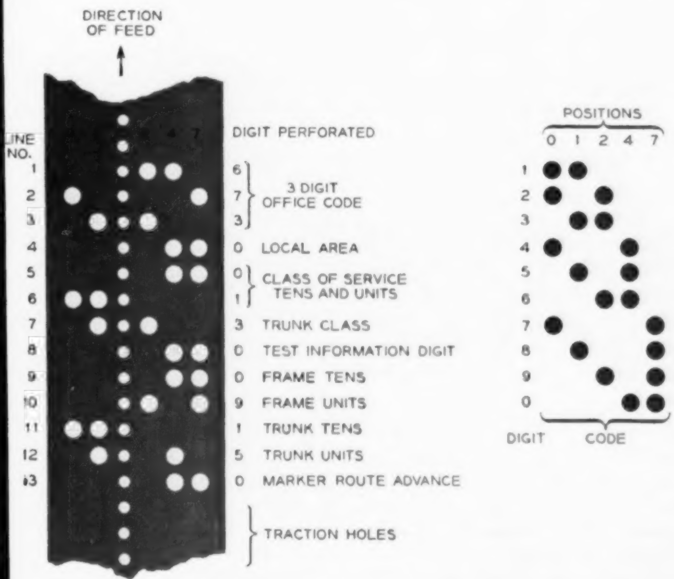


Fig. 5 — Drawing indicating enlarged section of tape perforated with information required for selecting one trunk.

may be made by running the reperforator under control of the transmitter-distributor. The reperforator copies on new tape the information read from the old.

The tests applied to each trunk are tests that years of experience have found to be desirable. Among these are tests of the trunk charging features; ringing and tripping features; timed release features; and an over-all test that includes the relays in an outgoing trunk, the associated cable pair, and the incoming trunk or selector in the distant office. In addition to the above, tests may be restricted to a single feature, such as a test of the continuity and polarity of the cable pair associated with each outgoing trunk. Flat rate, message rate, coin and AMA trunks may be tested.

If the testman wishes to seize and test a particular trunk he may do so by keying the information usually furnished by the tape. The same relays that record the tape information respond to the operated keys. Operation of a "start" key then causes a marker to be attached, and the trunk is seized as already described.

The test circuit may be used to test trunks associated with one, two, or three marker groups. It may be used simultaneously with the manual trunk test circuit that forms a part of the master test frame, and in any one of the three marker groups served. The relays, switches and timing devices used in testing are mounted on a relay bay equipped with a writing shelf and with "pigeon holes" for storing useful testing data. A key and lamp panel is located above the writing shelf. Figure 6 shows a preliminary arrangement of the control panel. The Teletype equipment is mounted nearby on a small table designed to provide easy access to the equipment for servicing and for tape handling. As tape leaves the reading element of the transmitter-distributor, or as new tape leaves the reperforator, it is collected by the winding reel and takes the form of a small ring that may then be stored in space provided in the Teletype table. No rewinding is necessary between successive usages, because the tape is fed from the inside of the tape ring previously formed by the winding reel.

The new test circuit offers the attractive feature of unlimited flexibility in the order of selecting

Fig. 6 — V. J. Acquaviva operates the test circuit control panel of the laboratory model.

trunks for testing. When trunks are added or rearranged for traffic reasons, no wiring changes are necessary in the test frame. Only the tape information requires modification. The tape method of control also provides for the grouping of trunks so that they may be tested in accordance with trunk routes, or by equipment sequence on a trunk link frame, or by sequence in AMA recorders. Separate tapes may be prepared – tailor-made to suit each grouping arrangement. The test circuit imposes no limitations on tape length. The maximum length, however, will seldom exceed 50 feet. A tape of that length will serve about 500 trunks.

The new test circuit will be used in large No. 5 crossbar offices, especially those serving metropolitan areas where large trunk groups are required.

THE AUTHOR

H. D. Cahill joined the Installation Department of the Western Electric Company in 1923, spending the next year on installation of new dial equipment. In 1924 he transferred to the Engineering Department, now known as Bell Telephone Laboratories, where he was concerned with the design of various telephone switching circuits for both manual and dial exchanges. During World War II, he designed equipment for the Armed Forces and trained military personnel in its use. Immediately following the war, he assisted in the design of mathematical computers, and for the past few years has been engaged in the design of central office circuits for AMA. Mr. Cahill received the B.S. degree in E.E. from the University of Maine in 1923.

R. K. Honaman Addresses Utility Commission Engineers

"The communications industry has never assumed a 'static way of life' but has had to look constantly into the future in order to meet the demands placed on it," R. K. Honaman, Director of Publication, recently told the 32nd Annual Conference of Utility Commission Engineers in Ottawa.

Speaking on *Progress in Communications Developments*, Mr. Honaman cited the Bell solar battery, one of the Laboratories' most recent developments, as another step in the search for new and better ways to do the job.

Tracing telephone progress, he said that the landmarks in the history of the telephone are in almost every case "monuments to someone's refusal to be content with what was then available." Mr. Honaman added that the nature of the telephone business has always been to discard the traditional without regret and to continue the search for something new and better.

"The progress, of course, has been steady, but not always uniform," he told the conferees. "At several points along the path to today's technology, whole vistas have been exposed. Then there are periods of less spectacular, though highly important progress. Along the entire course, we see evidence of skillful application of science.

"The creation of something new carries with it a certain responsibility," he said. "This sense of responsibility is always present in the minds of those who create for a public service industry. The communications industry, which was itself born of invention, exists because the public wishes it to exist. Thus the telephone people have always been conscious of their public responsibility. As they brought forth new things, they have made them available to others."

The Laboratories, Mr. Honaman concluded, has always had the practical problem of helping to provide communications equipment at the lowest possible cost consistent with maintaining a high standard of performance. He said that even in the face of rapidly rising costs, the Laboratories has helped to provide the telephone user with services of increasing value and speed and quality.

"I would not have you think," he said, "that research and development can hope to solve all our problems if the trend toward higher cost continues. But we have every confidence that it can be a big help in the future and we certainly propose to do our best."

Talks by Members of the Laboratories

During June, a number of Laboratories people gave talks before professional and educational groups. Following is a list of the speakers, titles, and places of presentation:

Electron Tube Conference, Orono, Maine

Brangaccio, D. J., see Tien, P. K.

Cutler, C. C., Electron Velocity and Current Measurements on the Spent Beam of a Traveling Wave Tube.

Danielson, W. E., Some Calculations Concerning Wave Propagation on Finite Electron Streams in Regions of Accellerating Potential.

Goddard, C. T., Factors Associated with Broad-Band Amplification with Tetrodes.

Hines, M. E., Saloom, J. A., and Hoffman, G. W., Ion Drainage in Magnetically Focussed Electron Streams.

Hoffman, G. W., see Hines, M. E.

Karp, A., and Yocom, W. H., Backward Wave Tube for Millimeter Waves.

Kompfner, R., Traveling Wave Tube Attenuators.

Laico, J. P., Mechanical Design Factors in Traveling-Wave Tube Operation.

McDowell, H. L., Measurements of the Conversion of Amplitude to Phase Modulation in a TWT.

Poole, K. M., Emission from Hollow Cathodes.

Quate, C. F., Power Series Solution and Measurement of Effective QC in Traveling Wave Tubes.

Reed, E. D., Millimeter Wave Generation by Low Voltage Reflex Klystrons.

St. John, G. E., Variation of Noise Figure in a Traveling Wave Tube.

Saloom, J. A., see Hines, M. E.

Saloom, J. A., Focussing Properties for Pierce Electron Guns.

Talpey, T. E., Limitations Arising from Non-Uniform Current Distribution between Grid Wires in Close-Spaced Tubes.

Tien, P. K., and Brangaccio, D. J., Electron Beam Focussing by Bifilar Helices.

Yocom, W. H., see Karp, A.

I.R.E. – A.I.E.E. Semiconductor Conference, Minneapolis, Minnesota

Brattain, W. H., and C. G. B. Garrett, Surface Properties of Semiconductors.

Buehler, E., Hannay, N. B., Tanenbaum, M., and Valdes, L. B., Si Junction Transistors.

Christensen, H., Surface "Channel" Detection Method for Semiconductors.

Corey, H. E., Reproducible Bonded Germanium Diodes.

Dacey, G. C., and Foy, P. W., Present Status of the Field Effect Transistor.

Ditzenberger, J. A., see Fuller, C. S.

Early, J. M., Experimental p-n-i-p Transistors.

Ebers, J. J., see Miller, S. L.

Foy, P. W., see Dacey, G. C.

Fuller, C. S., and Ditzenberger, J. A., The Diffusion of Boron and Phosphorus into Silicon.

Garrett, C. G. B., see Brattain, W. H.

Goss, A., Silicon-Germanium Alloys.

Hannay, N. B., see Buehler, E.

Keene, F. R., see Warner, R. M., Jr.

Kleinman, D. A., see van Roosbroeck, W.

Law, J. T., A Mechanism for Water Induced Excess Reverse Dark Current on Grown Germanium n-p Junctions.

Lee, C. A., see Logan, R. A.

Logan, R. A., and Lee, C. A., Device Fabrication by Solid Phase Diffusion.

Logan, R. A., and Schwartz, M., Thermal Effects on Lifetime in Germanium.

Miller, L. E., Mechanisms for the Negative Resistance Regions in Point Contact Collector Characteristics.

Miller, S. L., and Ebers, J. J., Avalanche Breakdown and Multiplication in Germanium (and Si).

Moll, J. L., and Wilson, D. K., Silicon p-n-p Transistors.

Pfann, W. G., Temperature-Gradient Zone-Melting.

Schwartz, M., see Logan, R. A.

Tanenbaum, M., see Buehler, E.

Valdes, L. B., see Buehler, E.

van Roosbroeck, W., and Kleinman, D. A., Theory of the Solar Battery.

Warner, R. M., Jr., Mechanical & Electrical Comparison of Five Types of Ohmic Contacts to Germanium.

Warner, R. M., Jr., and Keene, F. R., The Dependence of Cutoff Frequency on Resistivity and Forming in VHF Point-Contact Transistors.

Wilson, D. K., see Moll, J. L.

Zuk, P., High Frequency Parameters of Junction Photocells.

American Physical Society Meeting, Minneapolis, Minnesota

Ahearn, A. J., Ultra Violet Transmission and Alpha Bombardment Conduction Inhomogeneities in Diamond.

Allison, H. W., and Moore, G. E., Diffusion of Tungsten in Nickel.

Brown, W. L., see Shulman, R. G.

Buehler, E., see Fuller, C. S.

Christensen, H., Surface "Channel" Detection Method for Semiconductors.

Talks by Members of the Laboratories, Continued

American Physical Society Meeting, Minneapolis, Minnesota

Ditzenberger, J. A., see Fuller, C. S.

Fletcher, R. C., see Shulman, R. G.

Fuller, C. S., Ditzenberger, J. A., Hannay, N. B., and Buehler, E., Resistivity Changes in Si Induced by Heat Treatment.

Guldner, W. G., see Wooten, A.

Hannay, N. B., see Fuller, C. S., and Morin, F. J.

Hannay, N. B., Haynes, J. R., and Shulman, R. G., Interaction of Traps and Heat Treatments in Si.

Haynes, J. R., see Hannay, N. B.

Maita, J. P., see Morin, F. J.

Merz, W. J., Domains and Their Formation in Barium Titanate Single Crystals.

Moore, G. E., see Allison, H. W., and Wooten, A.

Moore, G. E., Wooten, L. A., and Morrison, J. The Excess Ba Content of Emitting Oxide Coated Cathodes.

Morin, F. J., Maita, P. J., Shulman, R. G., and Hannay, N. B., Impurity Levels in Silicon.

Morrison J., see Moore, G. E.

Reiss, H., Carrier Mobility in Semiconductors.

Shulman, R. G., see Hannay, N. B., and Morin, F. J.

Shulman, R. G., Brown, W. L., and Fletcher, R. C., Hole Trapping Due to Lattice Defects in Germanium.

Wannier, G. H., Corrected Values for the Charge Transfer Cross-section in the Noble Gases.

Wooten, L. A., see Moore, G. E.

Wooten, L. A., Moore, G. E., and Guldner, W. G., The Measurement of Excess Ba in Emitting Oxide Coated Cathodes.

Other Talks

Anderson, A. E., Junction Devices for Switching, Western Electric Show and Convention, Los Angeles, Cal.

Anderson, O. L., Internal Friction Studies in Vitreous Silica at Low Temperatures, Symposium on Crystal Chemistry as Applied to Ceramics, Rutgers University.

Baker, W. O., Relaxation Mechanics of Single Polymer Molecules, Brown University, Providence, R. I.

Bommel, H. E., Ultrasonic Attenuation and Velocity Measurements in Fused Silica at Low Temperatures, Acoustical Society Meeting, New York City.

Bonner, A. L., Servicing Center for Short-Haul Carrier Telephone Systems, Summer and Pacific General Meeting, Los Angeles.

Bozorth, R. M., Statistics of Magnetic Materials, American Society of Engineering Education, Symposium on Impact of Solid State Physics on Engineering, Pittsburgh.

Burton, J. A., Impurity Centers in Ge and Si, International Conference on Semiconductors, Amsterdam, Holland.

Gilman, G. W., Research and Development Trends in Global Communications, I.R.E. Symposium, Washington, D. C.

Heller, C. H., Design Standards Organization of Bell Telephone Laboratories, Standards Engineers Society, Newark, N. J.

Helm, H. A., Frequency Response Approach to the Design of a Mechanical Servo, ASME Meeting, Pittsburgh, Pa.

Herring, C., see Pearson, G. L.

Hohn, F. E., The Need for Training and Research in Non-Computer Aspects of the Theory of Digital Control Processes, Wayne University, Detroit, Mich.

Ingram, S. B., Professional-Scientific Curricula in Communications – Essential Requirements for Research and Development Engineering, American Society for Engineering Education, Urbana, Ill.

Jensen, A. G., The Evolution of Modern Television, 75th Semiannual Convention of SMPTE, Washington, D. C.

Jensen, A. G., On the History and Evolution of Modern Television, For Students in Television Course, University of Rochester, Rochester, N. Y.

Karlin, J. E., see Munson, W. A.

MacPherson, D. H., Concentrator-Identifier as Applied to Telephone Answering Service, Summer and Pacific General Meeting, Los Angeles.

Mason, W. P., Relaxation Mechanism in Fused Silica and Metals, Symposium on Acoustics and Liquids, Brown University, New Brunswick, N. J.

Merrill, J. L., Jr., Theory of E-Type Repeaters, A.I.E.E. Summer Meeting, Los Angeles, Cal.

Munson, W. A., and Karlin, J. E., The Measurement of Human Channel Transmission Characteristics – Acoustical Society of America, New York City.

Olmstead, P. S., QC Concepts Useful in OR, American Society for Quality Control Meeting, St. Louis, Mo.

Pearson, G. L., and Herring, C., Magneto-Resistance Effect and the Band Structure of Single Crystal Silicon, International Conference on Semiconductors, Amsterdam, Holland.

Rea, W. T., Military Communication Applications of Transistors, New York City.

Sharpless, W. M., A Colorimeter for Power Measurements at Millimeter Wavelengths, IRE-International Scientific Radio Union Joint Meeting, Washington, D. C.

Smethurst, J. O., E-Type Telephone Repeaters Description, Equipment and Testing, Summer and Pacific General Meeting, Los Angeles, Calif.

Thatcher, T. W., Jr., Bell Laboratories Work in Sumpter County (Rural Subscriber Carrier), Lions Club (June 7), Friendship Community Club (June 11), New Era Community Club (June 12), Americus, Georgia.

Treptow, F. W., A PBX Telephone Switchboard for Dispatching Service, Summer and Pacific General Meeting, Los Angeles, Calif.

Willard, G. W., Vibrating Liquid Surfaces as Generators of Bubbles and Drops, National Science Foundation Symposium on Acoustics and the Structure of Liquids, Brown University, Providence, R. I., and 25th Anniversary Celebration of the Acoustical Society of America, New York, N. Y.

Wintringham, W. T., Color Vision and Colorimetry, Seminar, Penn State College.

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